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MEASURED TEMPERATURES AND HUMIDITIES INSIDE CLOUDS FLAGSTAFF, ARIZONA - 1966

by

Albert R. Tebo

September 1969

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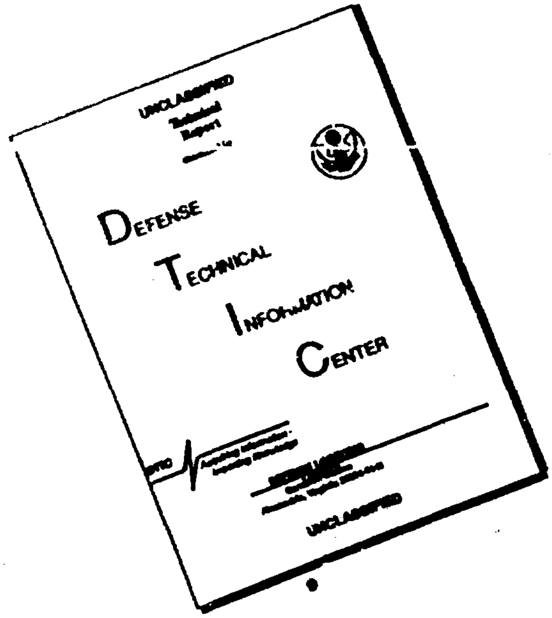

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TECHNICAL REPORT ECOM-3174

MEASURED TEMPERATURES AND HUMIDITIES INSIDE CLOUDS, FLAGSTAFF, ARIZONA - 1966

By

Albert R. Tebo

Atmospheric Modification Task Group
Atmospheric Sciences Laboratory

September 1969

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U. S. ARMY ELECTRONICS COMMAND
FORT MONMOUTH, NEW JERSEY

Abstract

Temperatures and humidities were measured in aircraft flights in July 1966 at Flagstaff, Arizona. Because of its rapid response and freedom from external influences, an Infrared Atmospheric Thermometer, sensitive to the 15-micrometer wavelength band, was used to provide reliable temperature measurements. Of the 46 traverses through clouds at altitudes up to 5.8 kilometers, all but one showed an interior lower in temperature than the ambient air by as much as 1.7°K. This characteristic seems to be associated with clouds that have ceased growing. Temperatures just below the clouds varied similarly with temperatures inside the clouds, and in about the same magnitudes. The air immediately outside the clouds was always warmer than the ambient air by as much as 1.0°K, except in the one case of the warmer cloud. A barium fluoride electric hygrometer, mounted in a vortex thermometer housing, was used to measure relative humidities. Its rapid response, better than 0.1 second, enabled it to delineate clearly the entry and exit of clouds. Its indication of humidity changes corresponded consistently with temperature changes throughout all flights.

The complete set of data is included to provide interested personnel information for related research in cloud physics since these data represent the first field experiments to determine temperatures inside and outside cumulus clouds with an Infrared Atmospheric Thermometer.

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MEASURED TEMPERATURES AND HUMIDITIES INSIDE CLOUDS, FLAGSTAFF, ARIZONA - 1966

INTRODUCTION

The desire for more detailed information on the development of thunderstorm clouds has necessitated improved techniques of measurement of atmospheric parameters. Recent advances in sensors and instrumentation for measuring temperature and humidity have enabled more rapid and accurate measurements to be made. Such instruments, aircraft-mounted, have made it possible to study the thermal structure and moisture content of clouds more precisely than ever before.

BACKGROUND

Using an infrared thermometer and a barium fluoride humidity sensor mounted in an Army C-47 aircraft, a program of atmospheric measurements was carried out at Flagstaff, Arizona, in July 1966. Five flights were made over a period of 6 days, at altitudes varying from 4.17 kilometers to 5.80 kilometers. Forty-six successful cloud penetrations were made, many of which were duplications at different altitudes. Cruising speed throughout all flights was a fairly steady 130 knots (240 kilometers per hour) indicated air speed. Atmospheric temperatures ranged from -5.9°C to +9.9°C, and relative humidities ranged from 75 percent to 100 percent.

The program was designed to determine the horizontal profiles of temperature and humidity through fair weather clouds (cumulus humilis to cumulus mediocris), and to study the variation of these profiles at several vertical levels through the clouds. Another aim was to study the consistency of the relationship between humidity and temperature through clouds.

In a previous program, cloud temperature measurements with the infrared thermometer had indicated that the inside of clouds was often measurably colder than the ambient air. A verification of this observation was another objective of the program.

With the use of these two rapid-responding sensitive detectors, it was hoped that much more detailed and accurate information could be obtained on the thermal structure and moisture content of clouds. For a better understanding of the cloud-forming process, it would have been necessary to have additional measurements of aircraft attitude, flight direction, wind shear and wind direction, updrafts, and downdrafts. Such data were available only sporadically; however, use was made of data from nearby radiosonde flights.

DISCUSSION

Flight Plan

It was planned to fly through layers of clouds at different altitudes and at various stages of development, and to fly through each chosen cloud several times at different levels in order to get the vertical variation of the horizontal profiles of both temperature and humidity. This vertical variation involves an undesired time variation, which cannot be avoided when using an aircraft limited to finite speeds.

Well-defined clouds were selected whenever possible in order to distinguish, on the records, the points of entering and leaving the clouds.

The speed of the aircraft was kept constant during penetration of clouds. The aircraft was further trimmed for level flight with hands off the controls during penetrations in order to read updrafts and downdrafts from the rate-of-climb meter. Notations were made whenever the aircraft was banking in order to exclude data taken during that time. It had been planned to fly back and forth through each cloud several times in rapid succession, but the difficulty in identifying the same cloud when the aircraft turned around was often so great that it was impossible to carry out this plan on many clouds.

Instrumentation

Temperature Sensor. The equipment used to measure the atmospheric temperature was an Infrared Atmospheric Thermometer, "IRAT" (described by A. Combs[1]). It used a thermistor bolometer as a detector, whose broadband sensitivity was limited by filters to the wavelength band 14.7 - 15.9 micrometers. The instrument was mounted in the open window of the aircraft, looking out horizontally with a field of view 40° wide by 10° high. In the 15-micrometer wavelength band, the instrument sees effectively only the carbon dioxide component of the atmosphere, the proportionate concentration of which is very uniform throughout aircraft altitudes. In this wavelength band, radiation directly from the sun or reflected from the clouds is negligible compared with that from the carbon dioxide. Hence, the sun's presence had no influence on the measurement of atmospheric temperature.

On the assumption that the total volume of carbon dioxide seen by the instrument acts as a black body, the instrument registers the correct temperature of the atmosphere. In clear air, the instrument sees horizontally a distance of about 200 meters at sea level, and one and a half kilometers at an altitude of seven and a half kilometers. At an altitude of four and a half kilometers, the instrument sees about two-thirds of a kilometer[2].

Inside a cloud, radiation from the water droplets dominates over radiation from the carbon dioxide so that the instrument sees a black body of water droplets and registers the correct temperature of the cloud. The horizontal path seen by the instrument in a cloud is no more than a hundred meters, and depends on the nature of the cloud. In the transition space from clear air to dense cloud, the instrument registers an integrated average temperature of atmosphere, representing a combination of air to a depth of half a kilometer or so and water droplets to a depth of about 100 meters. A detailed analysis of the seeing distance of the Infrared Atmospheric Thermometer will be given in a separate report.

Response time of the thermometer, which includes a potentiometric recorder, is given as 1.0 second for a 90% response. This instrument is sensitive to ± 0.1°C from about 0°C to +30°C, and is accurate to ±0.2°C in this range. During the 1 second of response, the aircraft travels about 67 meters at a speed of 240 kilometers per hour, which could be called the response distance of the instrument.

As previously stated, the Infrared Atmospheric Thermometer was mounted in a fixed position in the aircraft, looking out the window horizontally just behind the wing, in a direction about 30° backwards to avoid seeing the wing. Care was taken to make sure that the tail of the aircraft was not seen by the thermometer.

It was obvious that when the plane was banking, the thermometer looked either higher or lower than horizontal, and hence would register the temperature of the air off the horizontal. Because of this, no temperature values were used when the plane was banking.

Humidity Sensor. The barium fluoride film electric sensor consists of a glass or other electrically insulating substrate on which a film of barium fluoride, 0.3 micrometers thick, has been deposited over closely spaced metallic film electrodes. The electrical resistance between the electrodes varies with relative humidity. This sensor, developed by Frank E. Jones[3] of the National Bureau of Standards, was used by him in an axial flow vortex thermometer probe mounted under the belly of the aircraft. The measurements were recorded on an oscillographic-type recorder. Response time of the instrument, including recorder, was believed to be considerably better than 0.1 second.

The humidity recorder was calibrated frequently by Mr. Jones during each flight, and the calibrated humidity scales were placed on the charts by him. An additional correction has been included in the final records given here in the form of a constant multiplication factor, 1.06, to account for the variations due to pressure changes at the surface of the sensor . This correction was suggested in a report by R. E. Ruskin[4] of the Naval Research Laboratory, and confirmed by him in a personal communication to Mr. Jones. The factor 1.06 was determined by Mr. Jones.

Synchronization of humidity readings with temperature readings was accomplished by feeding the humidity signal simultaneously into a second pen on the temperature recorder. Synchronization of the records with passage through clouds was achieved by visual observation and by stop watches.

Other Instrumentation. Altitude and aircraft speed were read from the standard aircraft altimeter and air-speed indicator. The rate-of-climb meter on the aircraft was used to determine updrafts and downdrafts when penetrating clouds. Response time of this meter was better than one second.

Presentation of Data

For the analysis of the data, the passage through each cloud was categorized in terms of four vertical levels, designated as "Under Cloud Base," "In Cloud Base," "In Cloud," and "In Cloud Top." The category "Under Cloud Base" means that the aircraft was flying below the cloud base, but just underneath it. "In Cloud Base" means just inside the cloud at its base or skimming the base, and "In Cloud Top" means inside the cloud at its top. "In Cloud" means anywhere else inside the cloud. The majority of the data used pertains to traverses "In Cloud."

The data were extracted discretely from the chart records at 3-second intervals, except for data from a few clouds that were taken at shorter intervals and replotted, so that temperature and humidity are displayed on the same graph. Many points were plotted at $1\frac{1}{2}$-second intervals in order to show rapid variations of temperature and humidity. The time scale is taken from stop-watch measurements. The distance scale is computed on the basis of a constant air speed of 240 kilometers per hour. For simplicity in plotting the data, the indicated air speed was not corrected for altitude, even though it was realized that this could cause large errors in the time scale. It was felt that the validity of the temperature and humidity measurements was not affected by this choice.

Clouds were numbered in alphabetical sequence. Five clouds were split into two parts, identified by numerical subscript, because the aircraft actually flew rapidly in and out of clear spaces between segments of these clouds. The records show the segments as separate clouds, but generically they are part of the same cloud.

On the replotted graphs, the clear-air ambient temperature level is shown by a straight line running the whole length of the plot. Deviation from ambient temperature while in the cloud can be determined directly from the graphs. In most cases, the ambient temperature was the same on both sides of a cloud, but in three clouds there was a noticeable gradient, varying up to 0.35°C per kilometer.

Figures 1 - 46 show the replots of all these data. Figures 3, 5, 7, 8, 11, 15, 19, 22, 24, 34, 35, and 40 depict clouds for which the temperature data were omitted because they were unreliable. These clouds are identified by numerical sequence. They are displayed to demonstrate the fidelity with which the humidity sensor follows the outline of a sharply defined cloud and to show the rapidity of response of the sensor. In fact, the discrete plot does not do justice to the sensor, even when the points are plotted on an expanded scale. The original graphs indicate a response time of about 0.1 second.

The updrafts are indicated on the graphs at the times they were recorded. Negative values refer to downdrafts. Some pertinent data extracted from these graphs are given in the tables that follow the graphs.

Table 1 shows the differences between inside cloud temperatures and ambient air temperatures. The symbol UB means Under Base, IB means In Base, IC means in Cloud, and IT means In Top. The symbol 15-1 means 15 July, first flight, etc.; A_1, A_2, A_3 are subdivisions of the same cloud, A; and A1, A2 are traverses 1 and 2 through cloud A, etc.

Analysis of Results

Temperature: In every cloud, the temperature responded simultaneously with the changes in humidity. In all but one of the 46 clouds, the temperature decreased inside the cloud. Figure 36 shows a temperature decrease just before entering the cloud, but an increase inside the cloud. It is significant that this was the only cloud traversed more than twice, and that this was the first traverse. To explain this seemingly anomalous temperature data, it is suggested that this cloud was caught on the first traverse at a time when it was in the growing stage, and thus building up. This would account for the fact that the temperatures were higher inside the cloud than outside. (After the traverse, the cloud began to deteriorate.) This view was strengthened by the records of the second through the seventh traverse through this cloud, which showed the cloud spreading out to a considerable horizontal length, indicating a colder interior.

Observers confirmed that practically all of the clouds traversed during the flight program were dying clouds, as determined visually from the cockpit of the aircraft. This accounts for the fact that the interior of these clouds was consistently colder than the ambient air.

Table 1 shows the range of differences between the in-cloud temperature and ambient air temperature for the first four types of traverse: 1) Under Base, 2) In Base, 3) In Cloud, and 4) In Top. The depressions of temperature Under Base, In Base, and In Top are not significantly different, on the average, from that of In Cloud, although the maximum depression In Cloud is much greater, namely -1.7°C, compared to -0.8°C, -1.3°C, and -0.7°C, respectively. It is interesting that the temperatures just under the cloud vary in the same manner as the temperatures in the cloud, and with approximately the same magnitudes.

An interesting effect was noticed when passing through the clouds. In every case except the one shown in Figure 36, immediately before entry and after exit, the air was warmer than the ambient air. This one traverse showed lower temperatures immediately outside the cloud. Table 2 shows this effect clearly. The maximum rise in temperature was +1.0°C; the single decrease in temperature was -1.0°C.

The ambient air itself, outside the immediate vicinity of the cloud, also showed changes in temperature from one side of the cloud to the other. Table 3 shows the variation around each cloud and the horizontal gradient of temperature involved in this variation. The maximum variation was 0.7°C, and the maximum gradient was 0.35°C per kilometer.

Humidity

The barium fluoride humidity sensor indicated a consistent pattern of sharp increases in humidity immediately upon entering each cloud, which agrees very well with the pattern of temperature changes. It is noticeable that the humidity sensor responded faster to the entrance into the cloud than the temperature sensor. In fact, in many cases the designation of the cloud boundary was based on the initiation of the humidity response. The failure of the humidity sensor to indicate 100% relative humidity inside all the clouds, as would be expected, might be due to an unaccountable source of error. Certainly in some of the clouds the aircraft was going in-and-out of small segments of the clouds, thus passing through relatively cloud-free spaces that showed drops in humidity from the peaks reached on the densest parts of the cloud.

During the second flight on 20 July 1966, the humidity element did not recover completely from an excursion to 100% relative humidity. Subsequent traverses through clouds indicated incorrect minima, which are indicated in parentheses in Table 4. It is believed that the inside of the vortex housing for the humidity sensor became completely wet, and that the sensor was indicating this moisture content until it had all evaporated from the housing.

Further analysis of the humidity data will be deferred to a later report. The humidity data are included in this report mainly to show the close correspondence of variation of humidity and temperature when traversing a cloud, and to show the usefulness of the barium fluoride electric hygrometer in an aircraft as a rapid-responding sensor.

CONCLUSIONS

In flight tests, the Infrared Atmospheric Thermometer was shown to be a reliable, fast-responding instrument, capable of measuring accurately atmospheric and cloud temperatures at altitudes up to 5.8 kilometers, the limit of the tests. There is no reason why it could not perform just as well at altitudes greatly exceeding this. The practical limitation would be that the seeing distance of the thermometer becomes so large that the temperature measurement becomes spacially undefinable, especially when entering a cloud.

Because of its fast response, the Infrared Atmospheric Thermometer promises to be a useful tool for determining temperature profiles of both the clouds and the atmosphere, and to be particularly useful for delineating sharp temperature gradients.

The results of tests show that growing clouds have interiors that are warmer than ambient air, whereas clouds that have ceased growing have colder interiors.

The temperatures just under the clouds vary in the same manner as the temperatures inside the clouds, and in almost the same magnitude. Likewise, the temperatures in the cloud tops vary in the same manner and to almost the same extent as those in the body of the clouds.

When the cloud was colder than the ambient air, the air immediately before entry into and immediately after exit from the cloud was warmer than the ambient air. Hence, a traverse through a cloud always involved three temperature reversals. This is probably explainable in terms of the updrafts or downdrafts within the cloud and the counter flow outside the clouds. However, the recorded updrafts and downdrafts do not bear out this simple picture since there are often both updrafts and downdrafts within a single cloud.

The barium fluoride electric hygrometer was shown to be a very fast-responding instrument and to measure relative humidities in clouds more definitively than any other instrument. It promises to be a very useful adjunct to the radiation thermometer in the study of clouds from aircraft.

ACKNOWLEDGMENT

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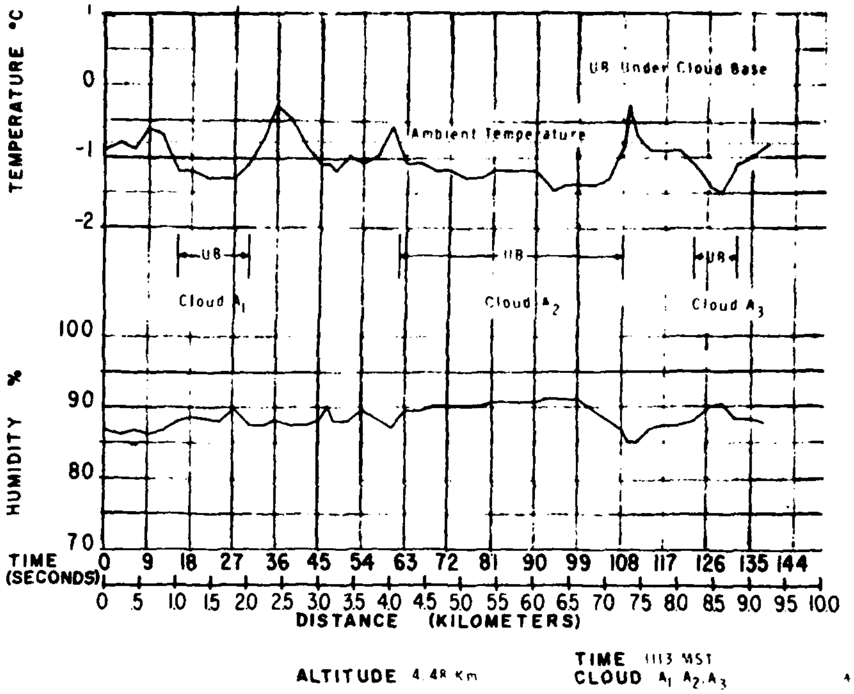

Figure 1. Cloud temperatures and humidities, 15 Jul 66, Flight No. 1, Cloud A_1, A_2, and A_3 .

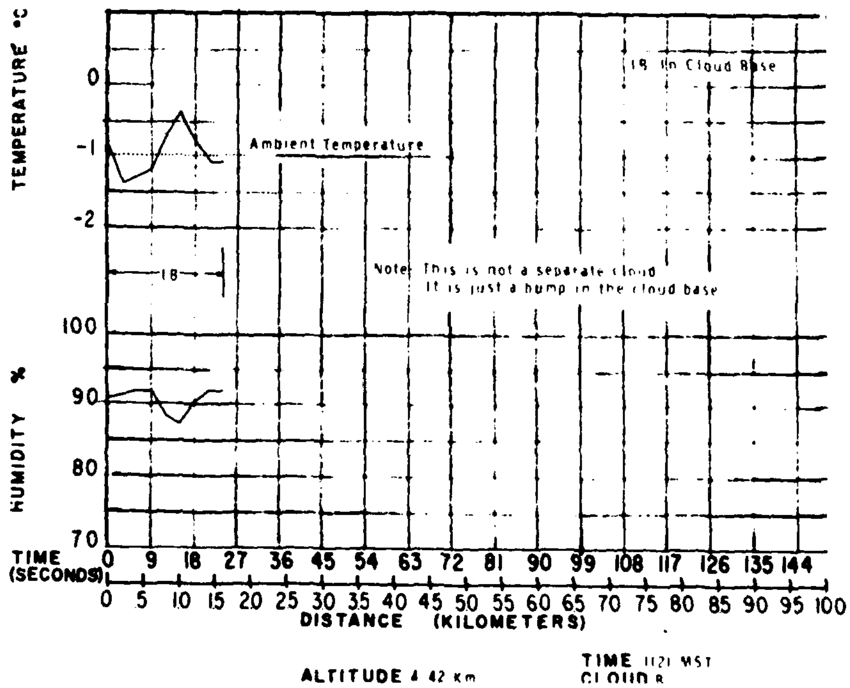

Figure 2. Cloud temperatures and humidities, 15 Jul 66, Flight No. 1, Cloud B.

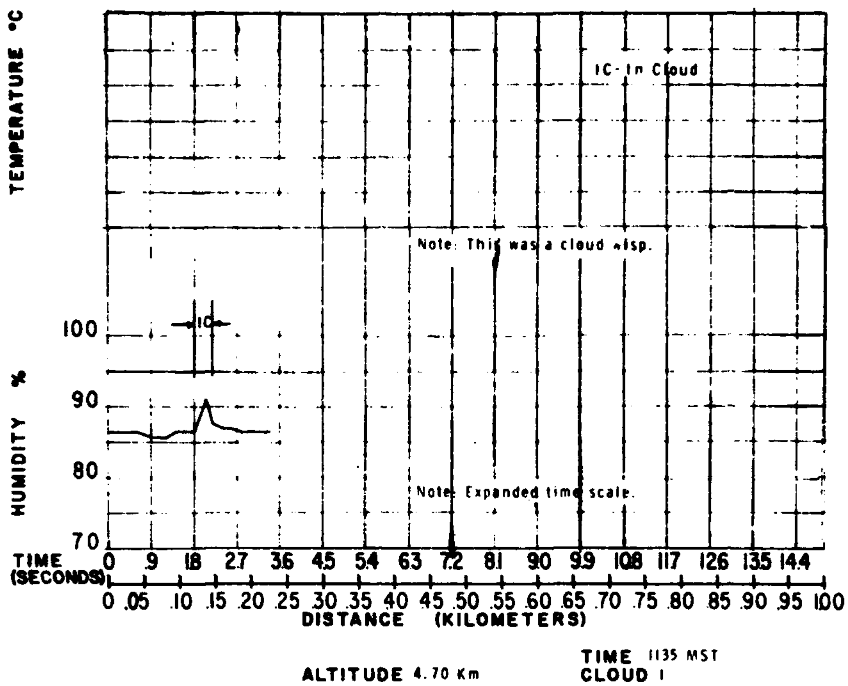

Figure 3. Cloud temperatures and humidities, 15 Jul 66, Flight No. 1, Cloud 1.

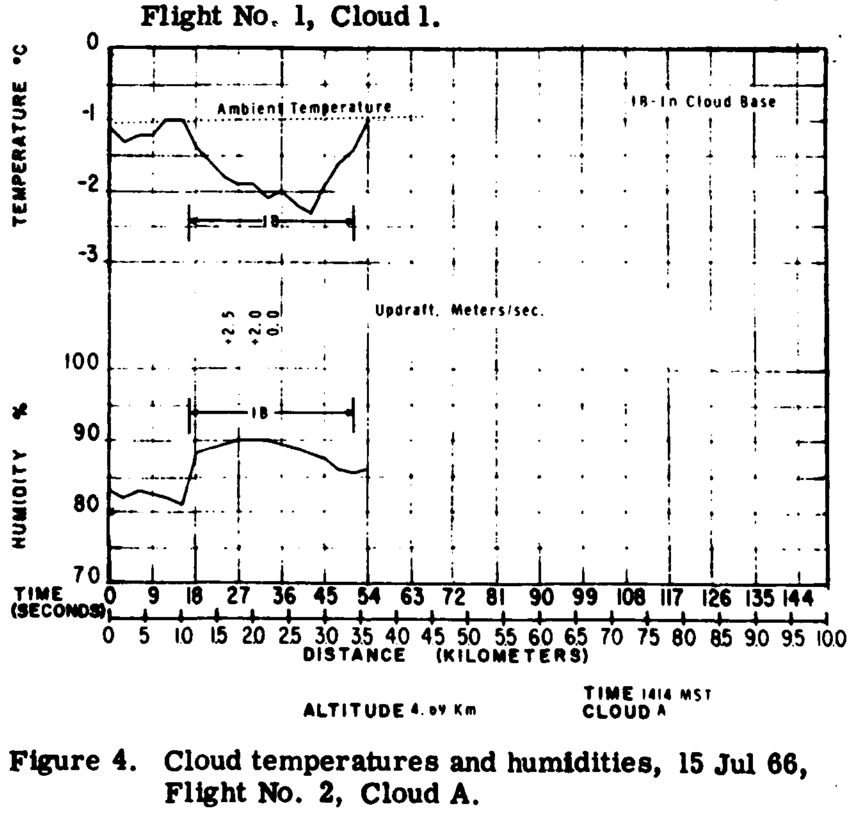

Figure 4. Cloud temperatures and humidities, 15 Jul 66, Flight No. 2, Cloud A.

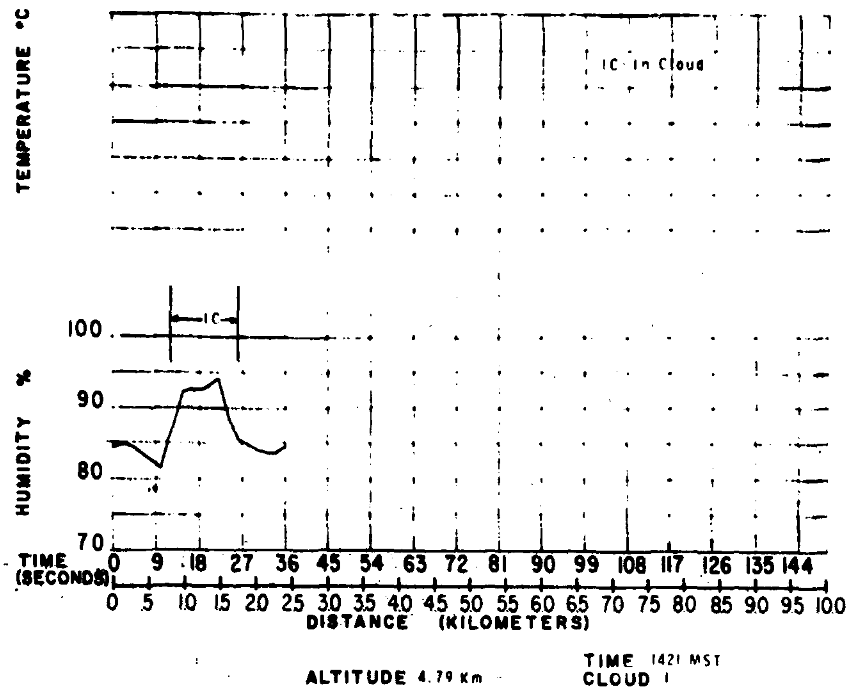

Figure 5. Cloud temperatures and humidities, 15 Jul 66, Flight No. 2, Cloud 1.

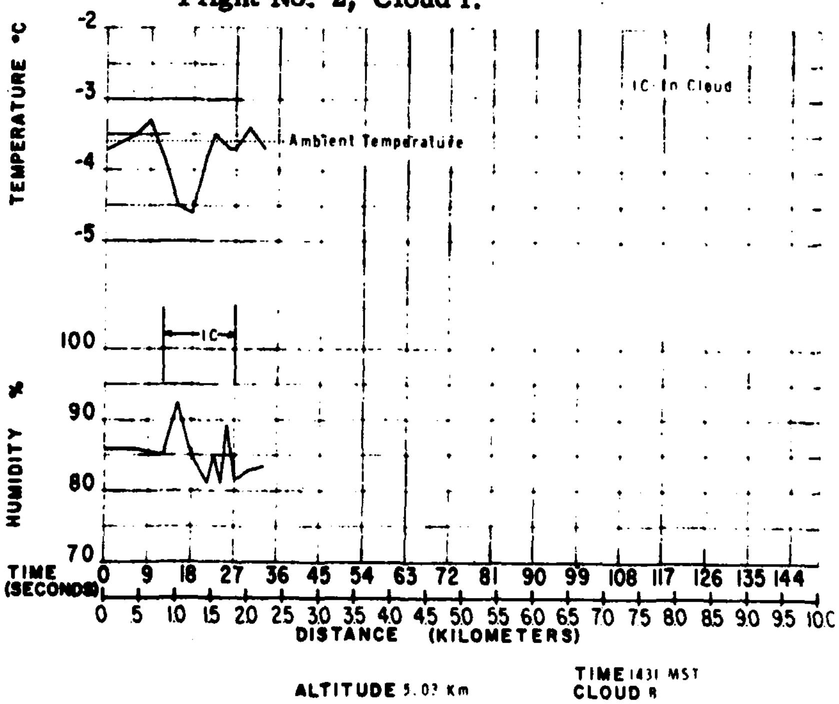

Figure 6. Cloud temperatures and humidities, 15 Jul 66, Flight No. 2, Cloud B.

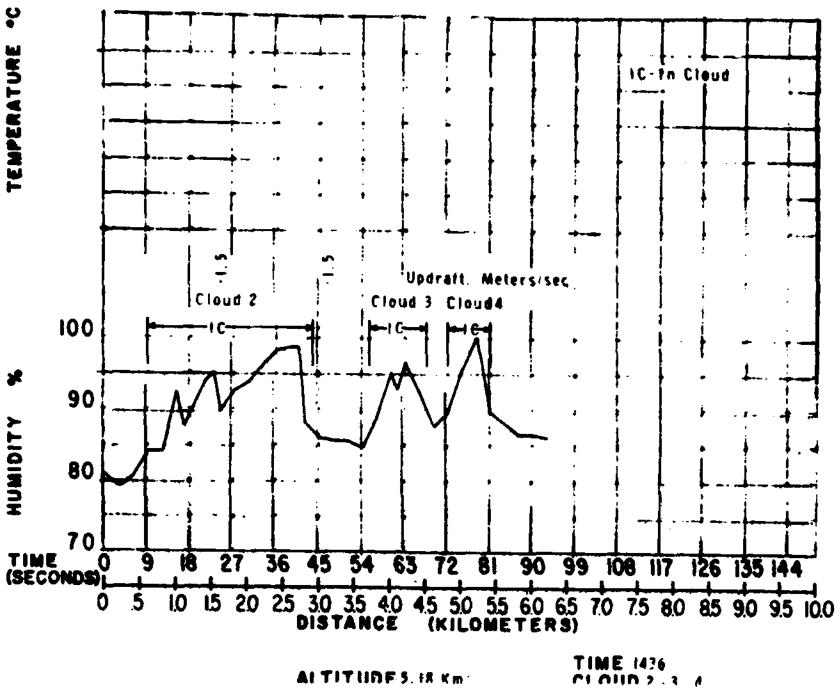

Figure 7. Cloud temperatures and humidities, 15 Jul 66, Flight No. 2, Cloud 2, 3, and 4.

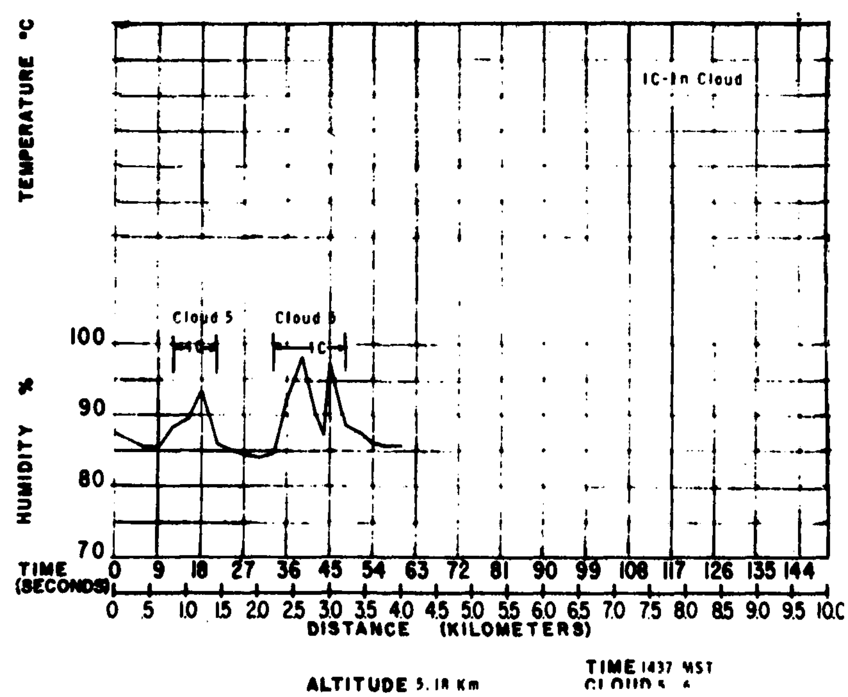

Figure 8. Cloud temperatures and humidities, 15 Jul 66, Flight No. 2, Cloud 6.

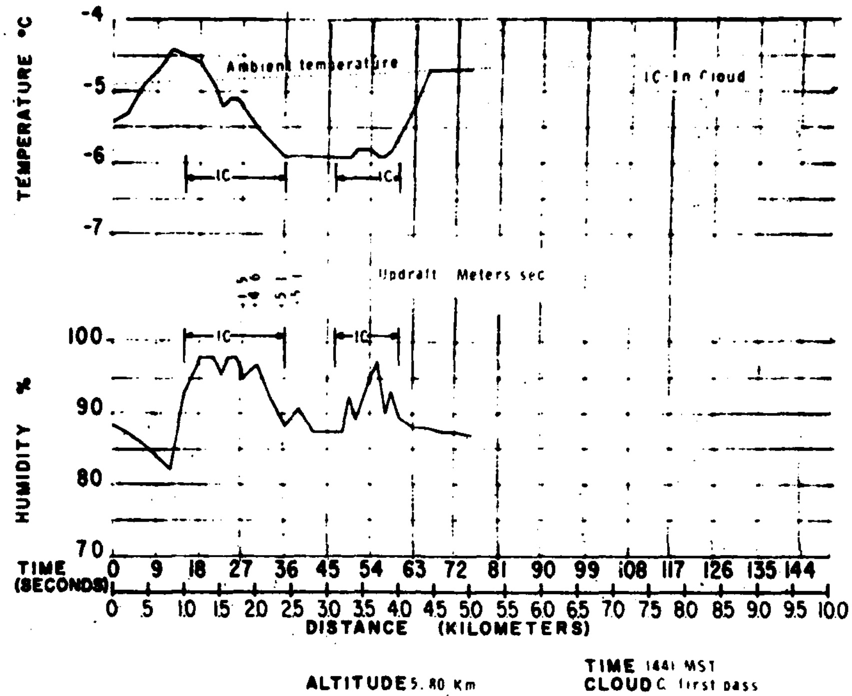

Figure 9. Cloud temperatures and humidities, 15 Jul 66, Flight No. 2, Cloud C (first pass).

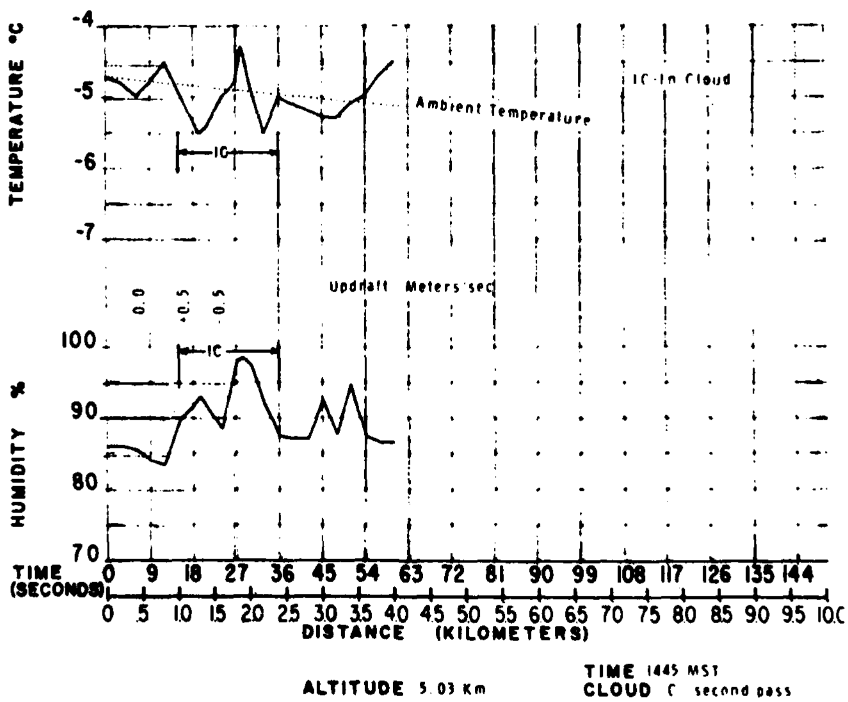

Figure 10. Cloud temperatures and humidities, 15 Jul 66, Flight No. 2, Cloud C (second pass).

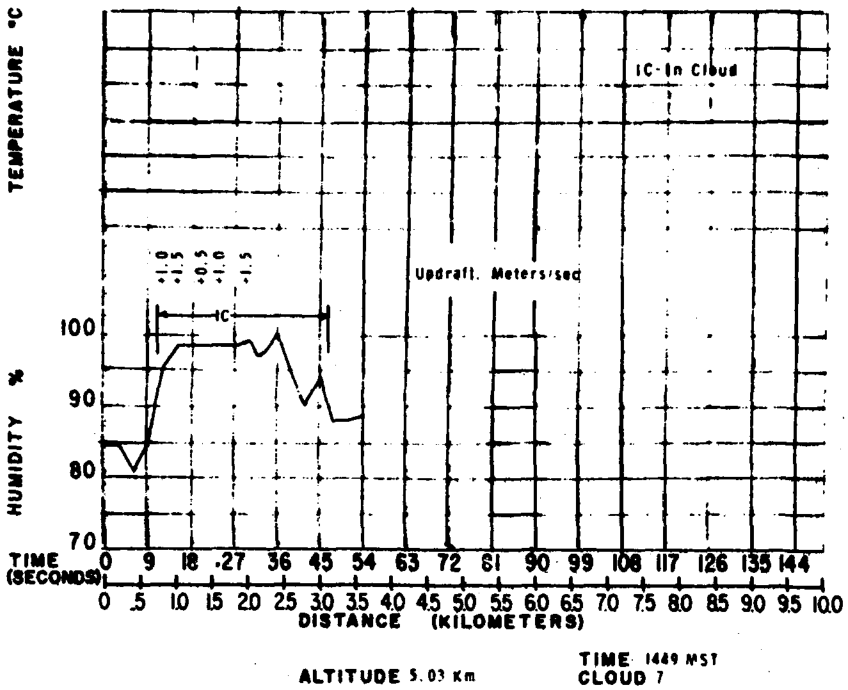

Figure 11. Cloud temperatures and humidities, 15 Jul 66, Flight No. 2, Cloud 7.

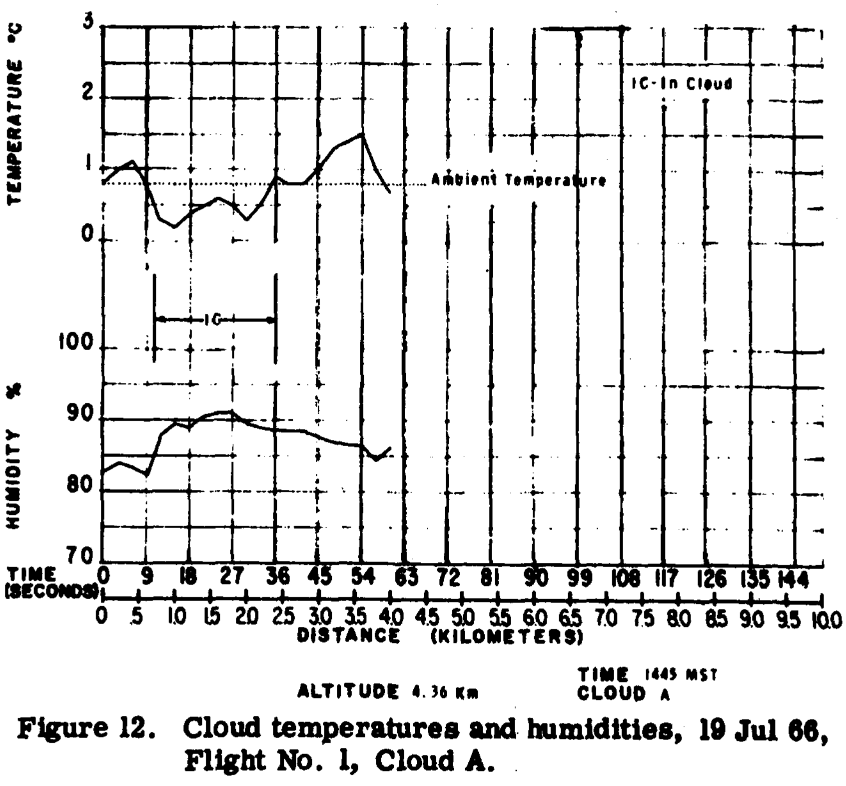

Figure 12. Cloud temperatures and humidities, 19 Jul 66, Flight No. 1, Cloud A.

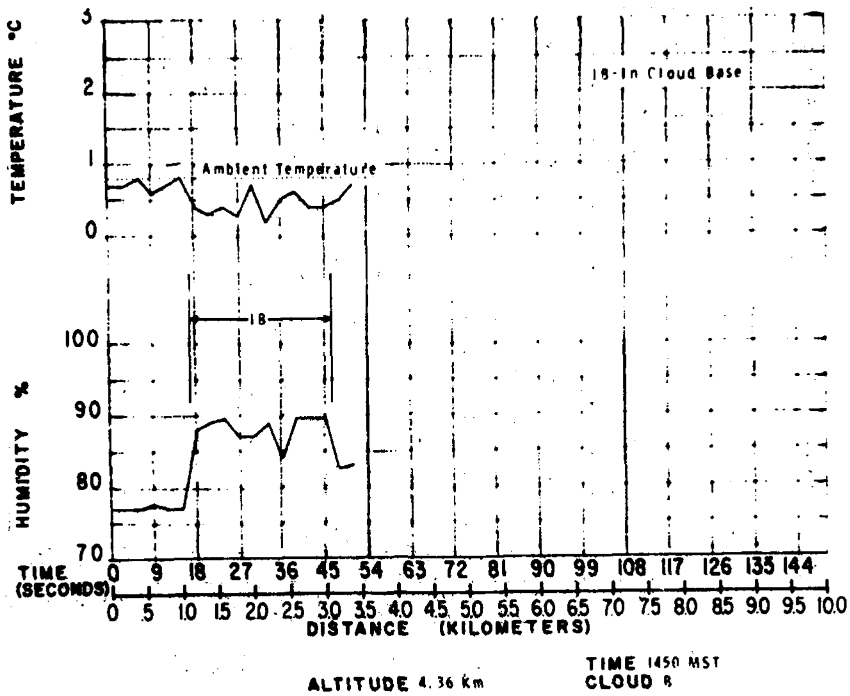

Figure 13. Cloud temperatures and humidities, 19 Jul 66, Flignt No. 1, Clouα B.

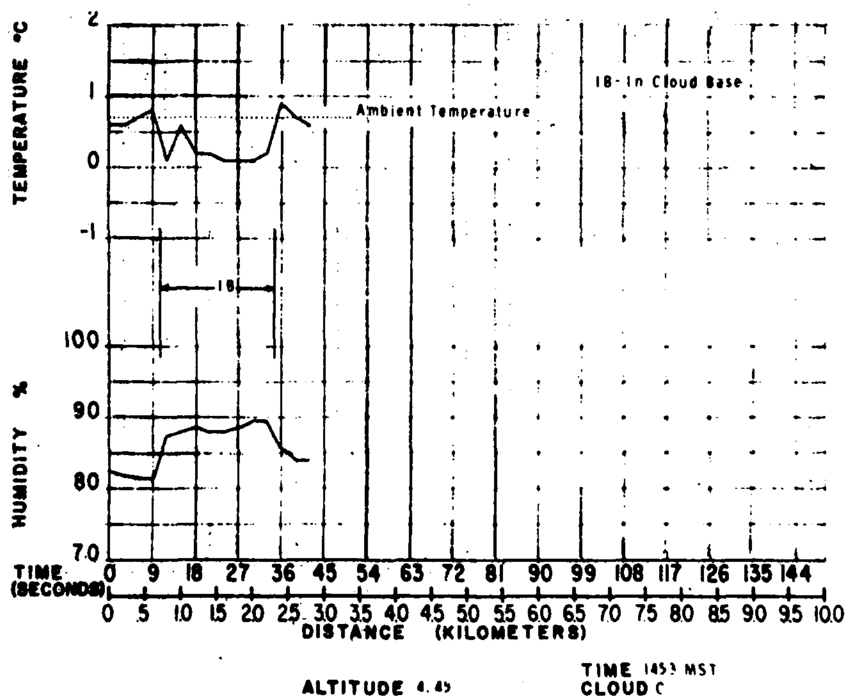

Figure 14. Cloud temperatures and humidities, 19 Jul 66, Flight No. 1, Cloud C.

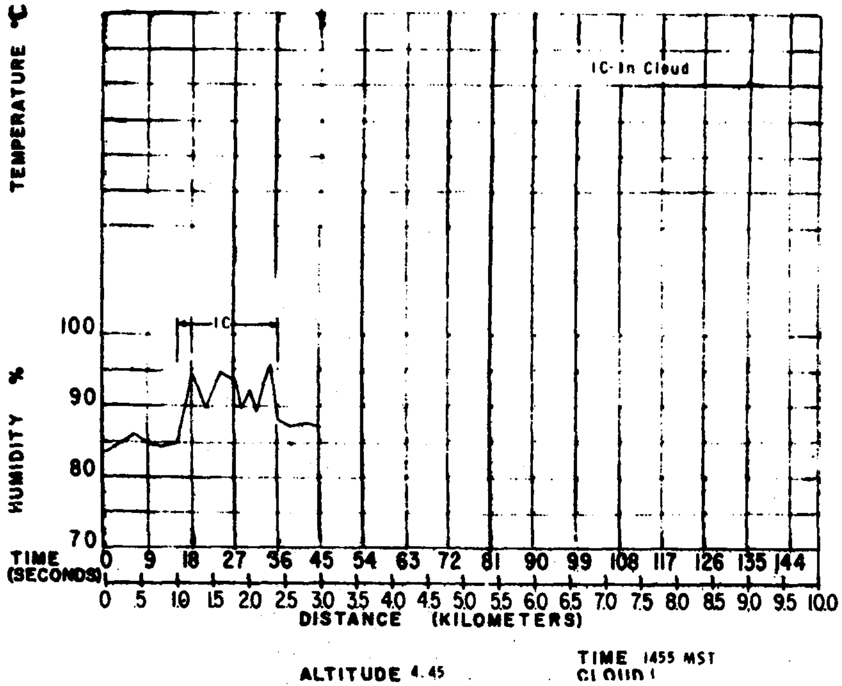

Figure 15. Cloud temperatures and humidities, 19 Jul 66, Flight No. 1, Cloud 1.

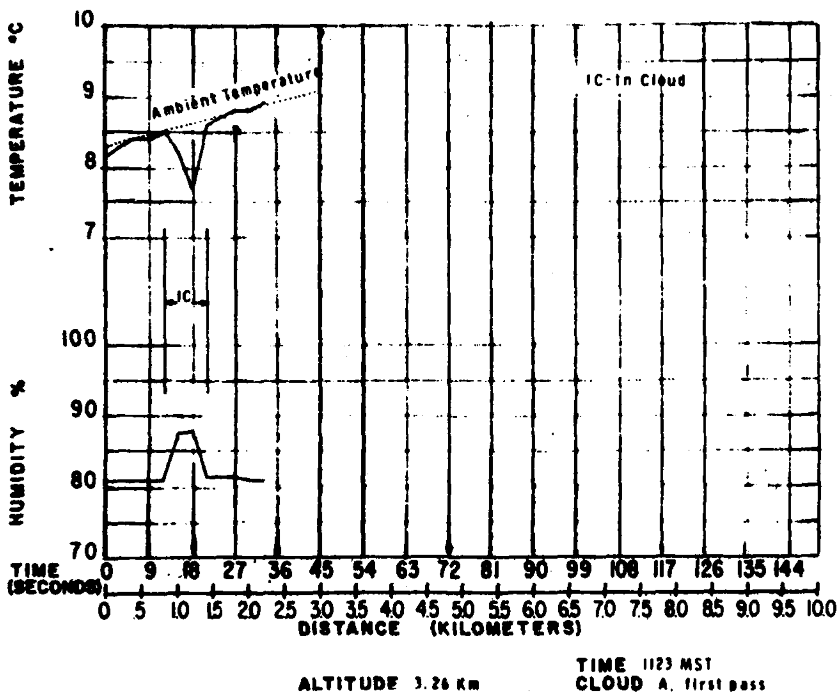

Figure 16. Cloud temperatures and humidities, 20 Jul 66, Flight No. 1, Cloud A (first pass).

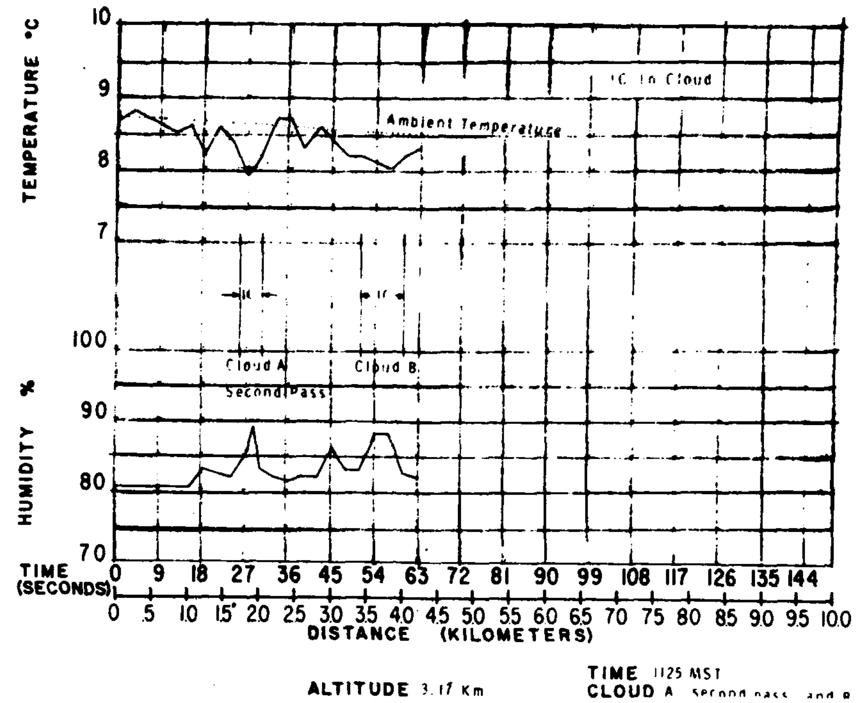

Figure 17. Cloud temperatures and humidities, 20 Jul 66, Flight No. 1, Cloud A (second pass) and Cloud B.

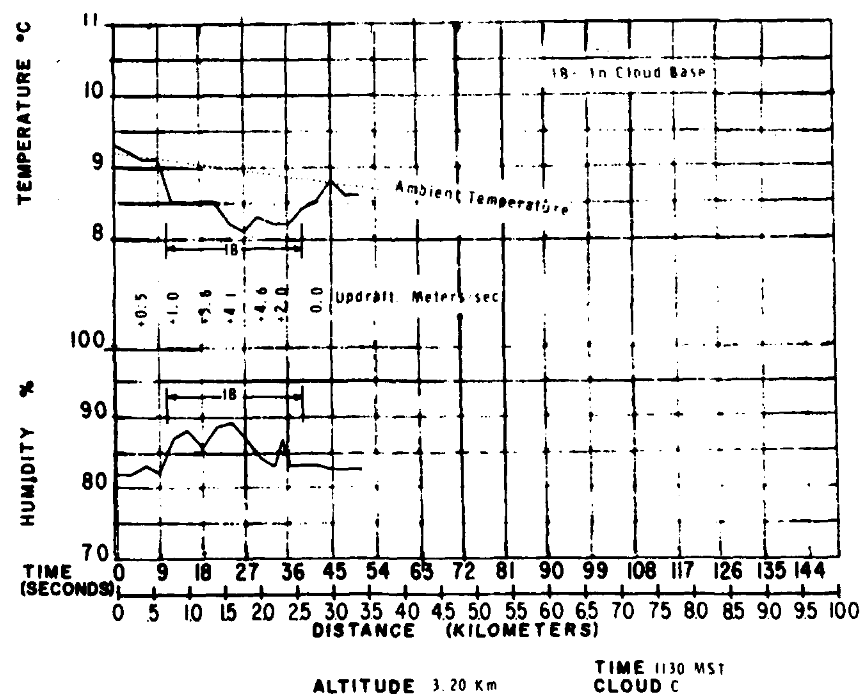

Figure 18. Cloud temperatures and humidities, 20 Jul 66, Flight No. 1, Cloud C.

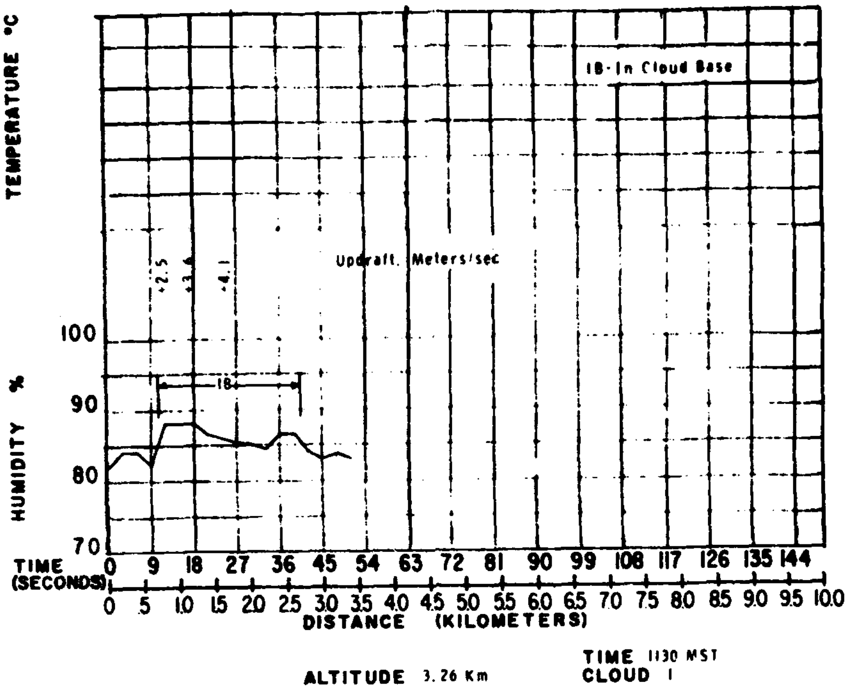

Figure 19. Cloud temperatures and humidities, 20 Jul 66, Flight No. 1, Cloud 1.

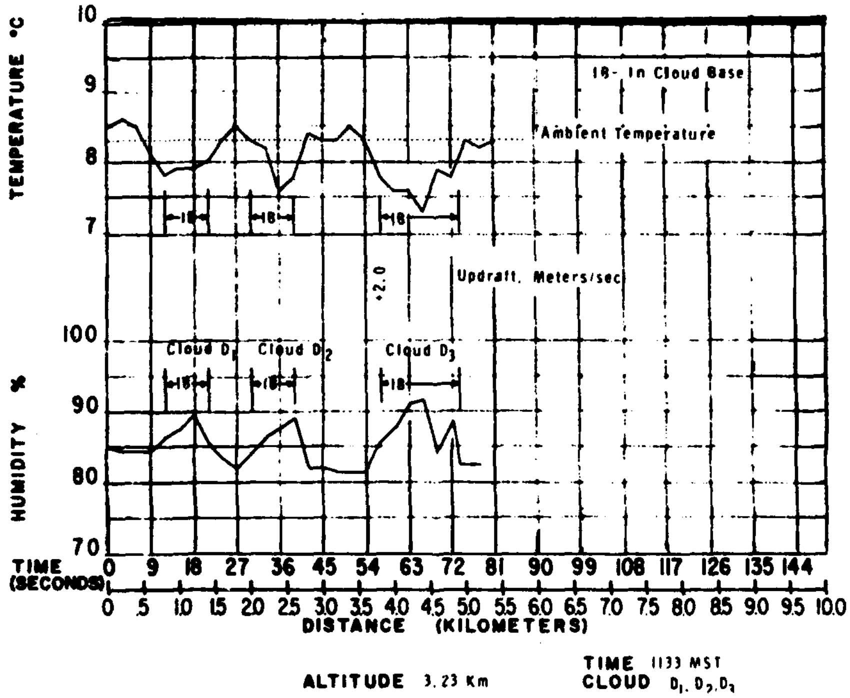

Figure 20. Cloud temperatures and humidities, 20 Jul 66, Flight No. 1, Cloud D_1, D_2, and D_3.

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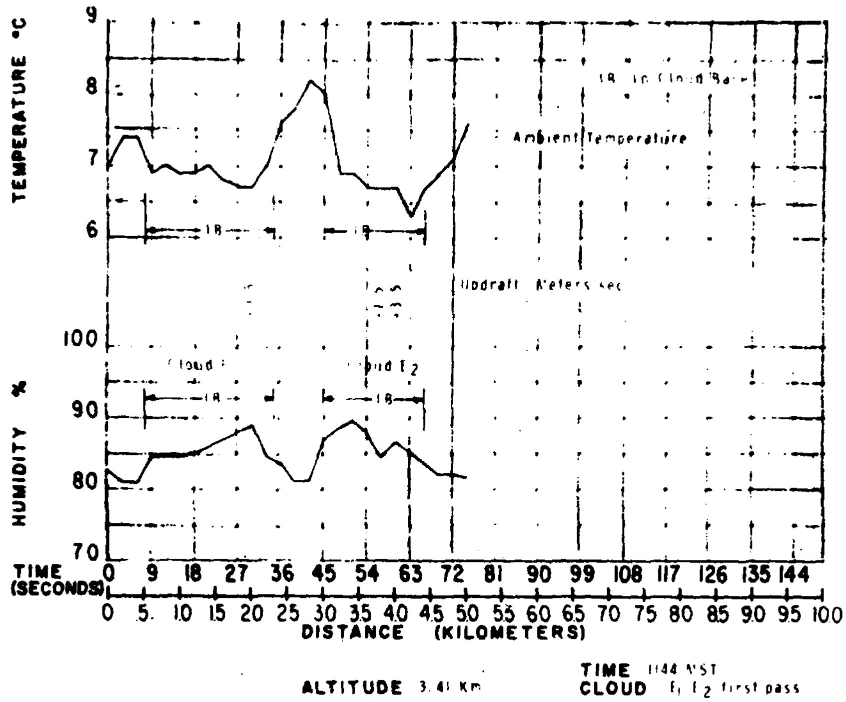

Figure 21. Cloud temperatures and humidities, 20 Jul 66, Flight No. 1, Cloud E_1 and E_2 (first pass).

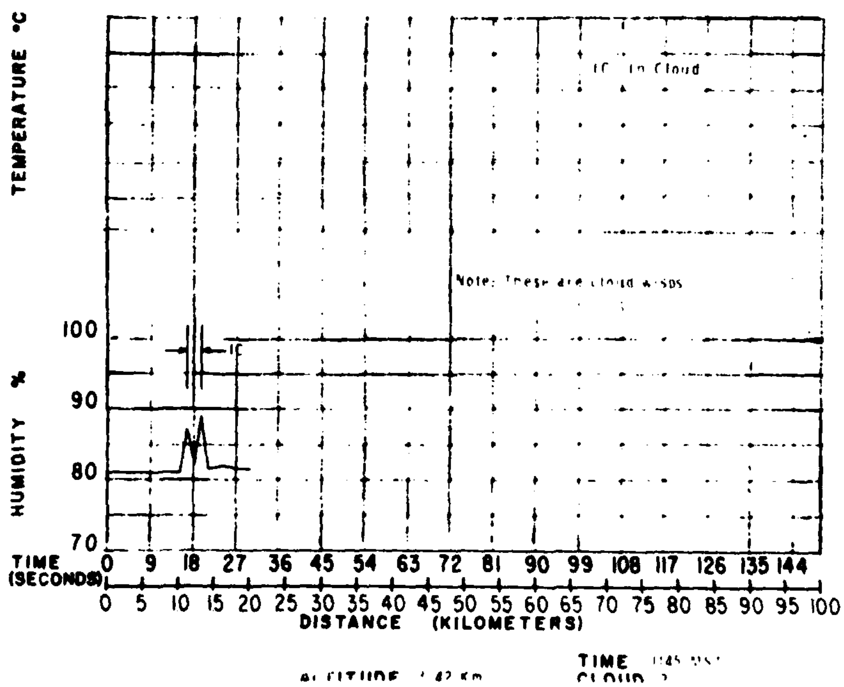

Figure 22. Cloud temperatures and humidities, 20 Jul 66, Flight 1, Cloud 2.

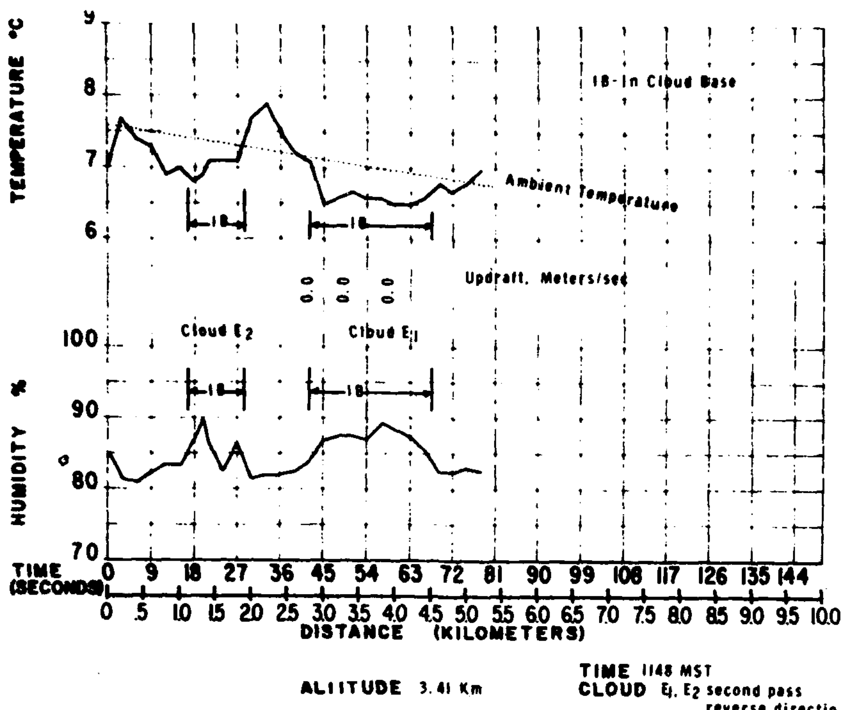

Figure 23. Cloud temperatures and humidities, 20 Jul 66, Flight No. 1, Cloud E_1 and E_2 (second pass, reverse direction).

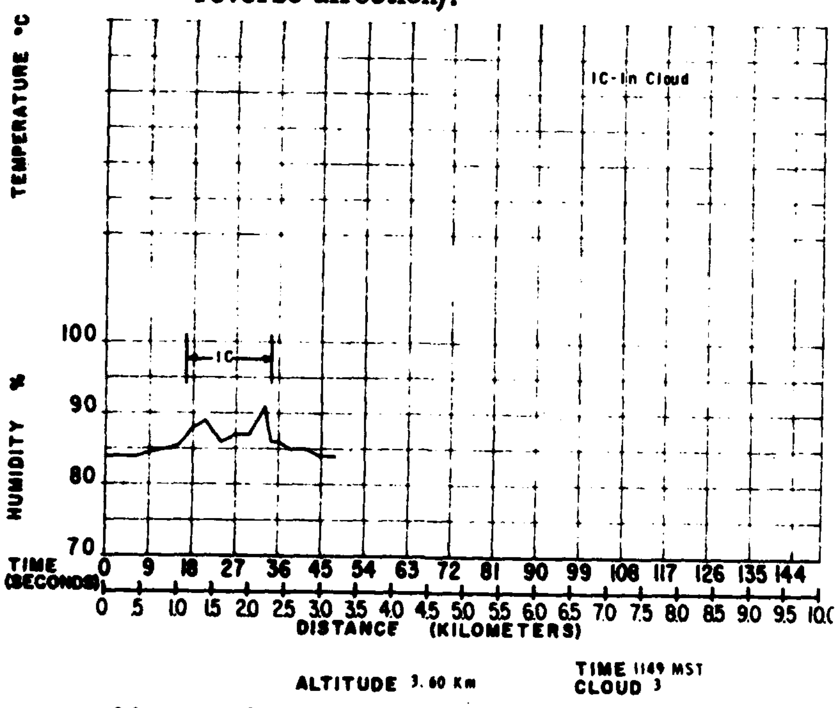

Figure 24. Cloud temperatures and humidities, 20 Jul 66, Flight No. 1, Cloud 3.

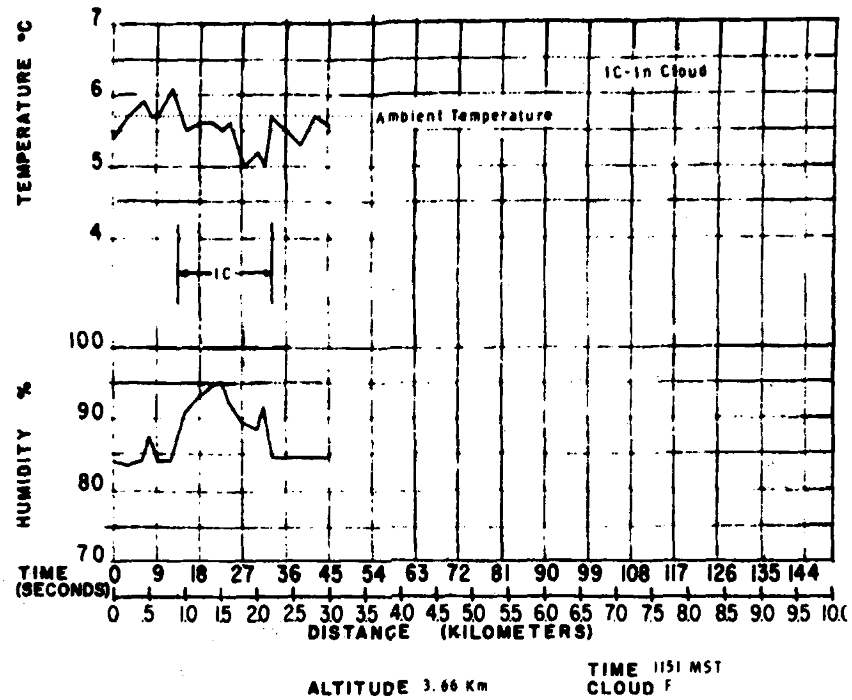

Figure 25. Cloud temperatures and humidities, 20 Jul 66, Flight No. 1, Cloud F.

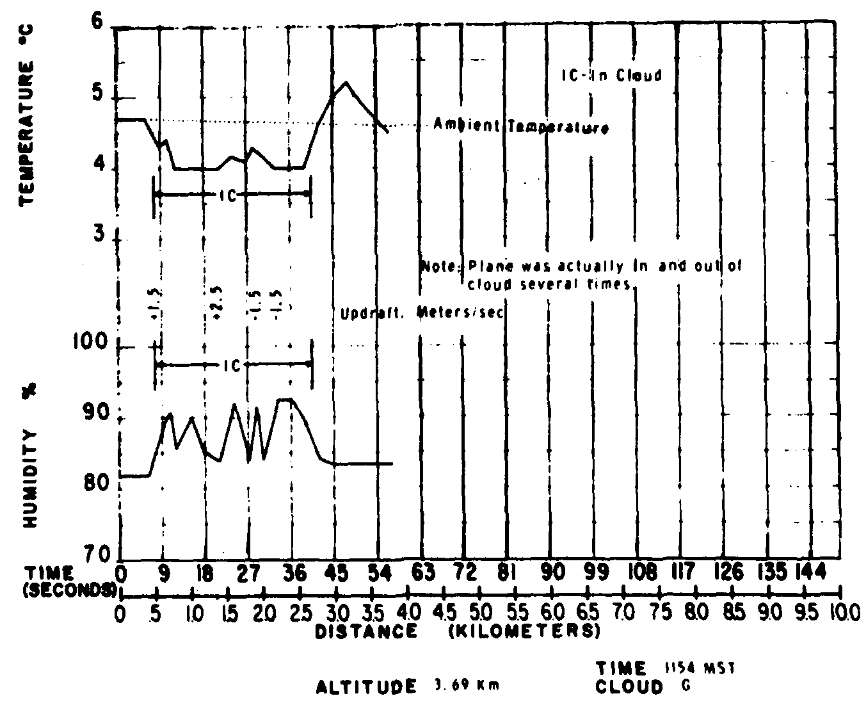

Figure 26. Cloud temperatures and humidities, 20 Jul 66, Flight No. 1, Cloud G.

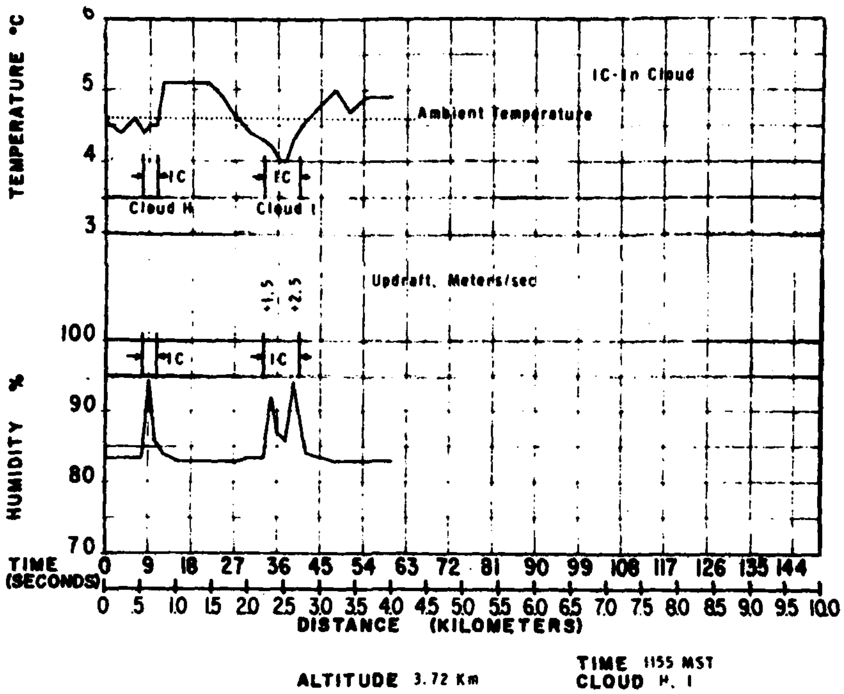

Figure 27. Cloud temperatures and humidities, 20 Jul 66, Flight No. 1, Cloud H, 1.

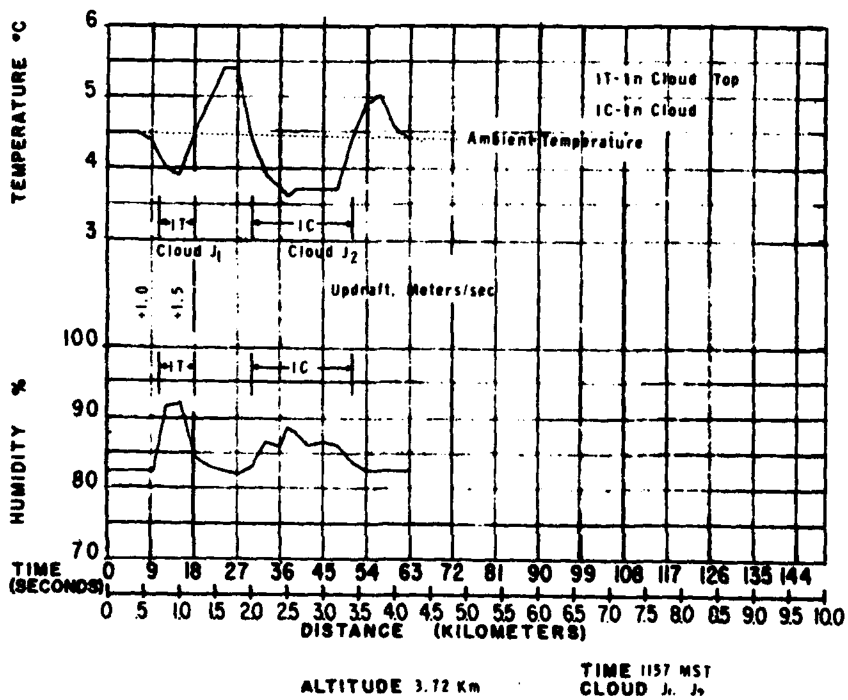

Figure 28. Cloud temperatures and humidities, 20 Jul 66, Flight No. 1, Cloud J_1 and J_2 ,

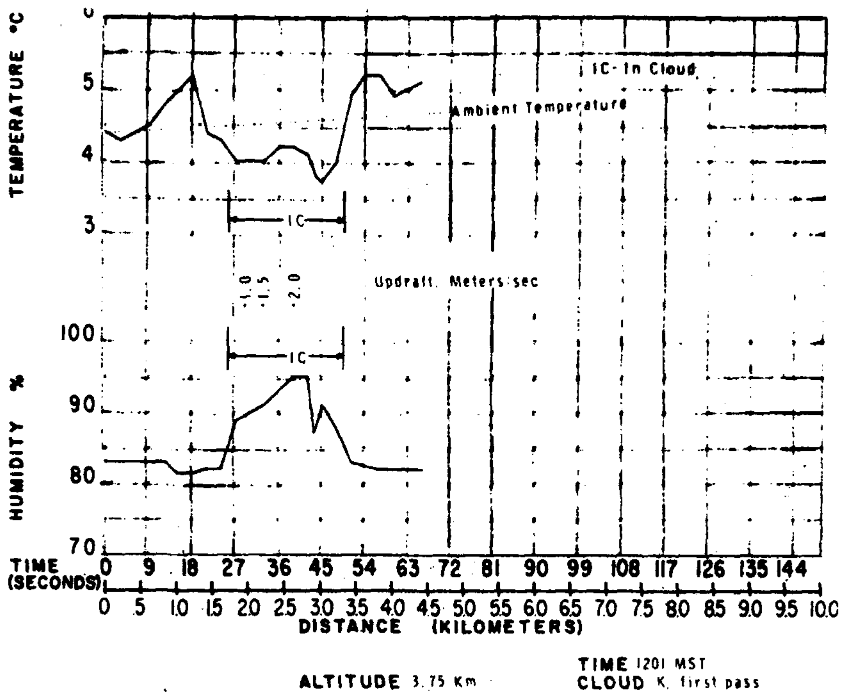

Figure 29. Cloud temperatures and humidities, 20 Jul 66, Flight No. 1, Cloud K (first pass).

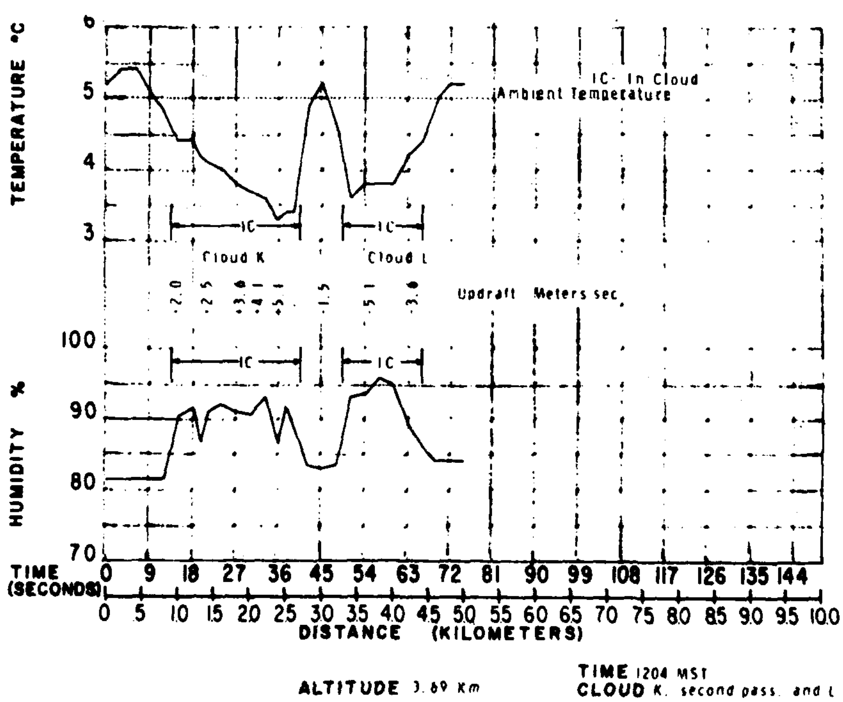

Figure 30. Cloud temperatures and humidities, 20 Jul 66, Flight No. 1, Cloud K (second pass) and Cloud L.

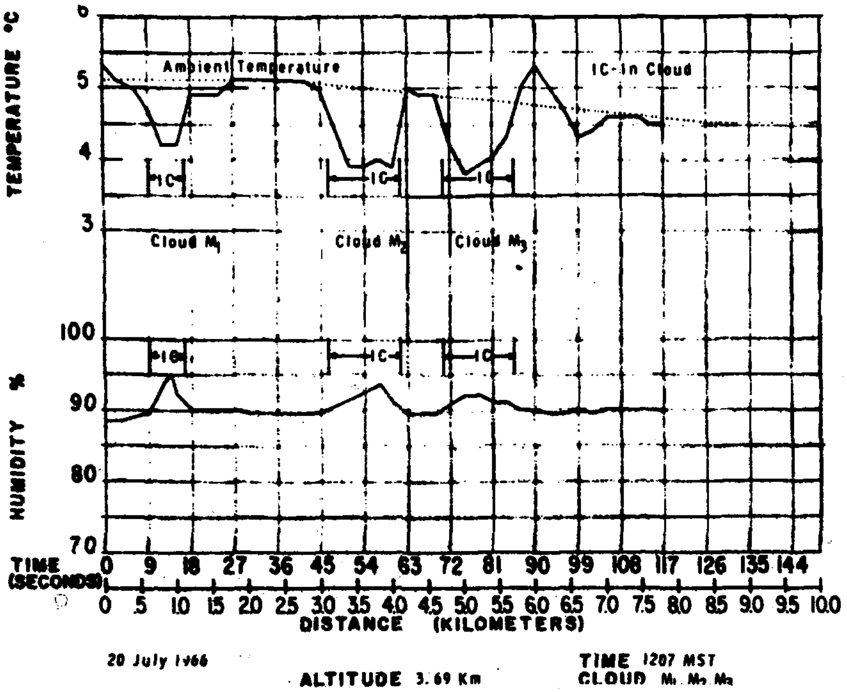

Figure 31. Cloud temperatures and humidities, 20 Jul 66, Flight No. 1, Cloud M_1, M_2, and M_3.

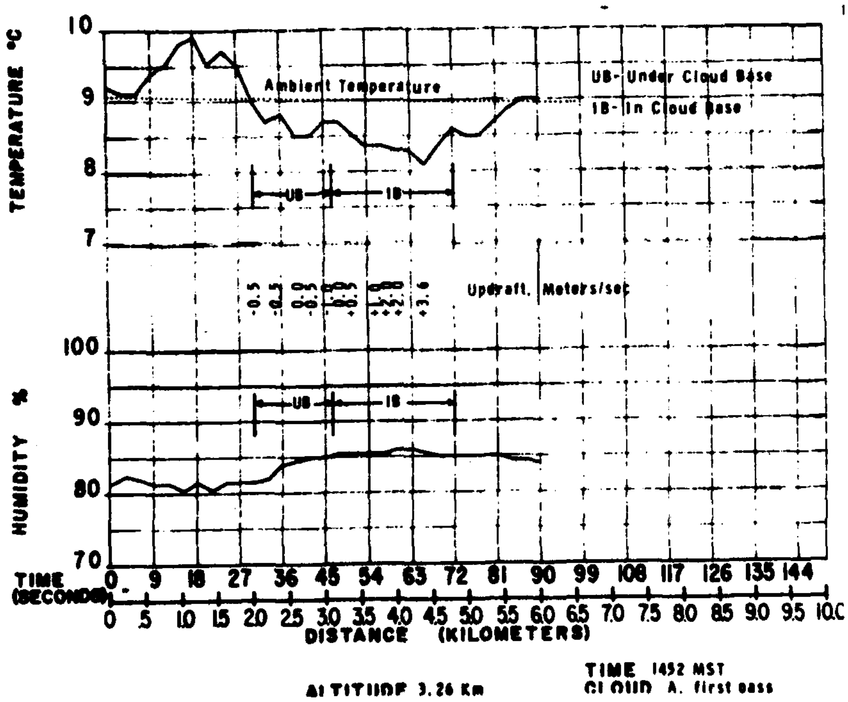

Figure 32. Cloud temperatures and humidities, 20 Jul 68, Flight No. 2, Cloud A (first pass).

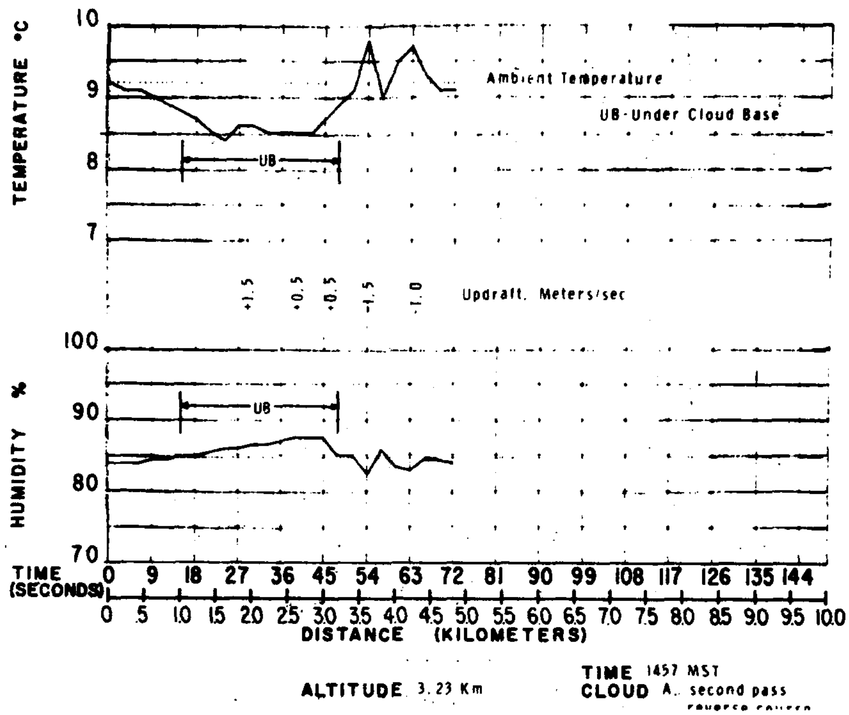

Figure 33. Cloud temperatures and humidities, 20 Jul 66, Flight No. 2, Cloud A (second pass, reverse course).

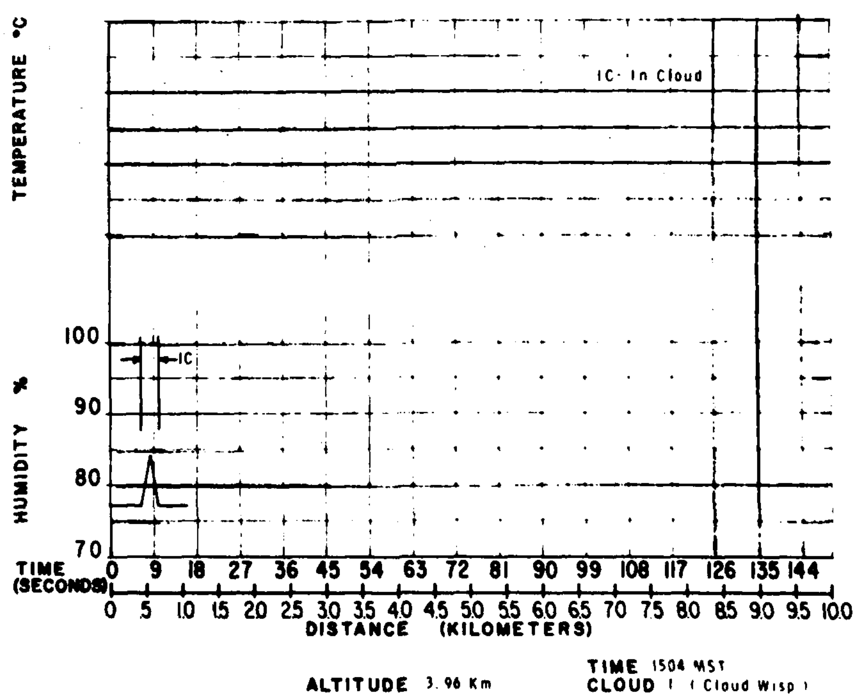

Figure 34. Cloud temperatures and humidities, 20 Jul 66, Flight No. 2, Cloud 1 (cloud wisp).

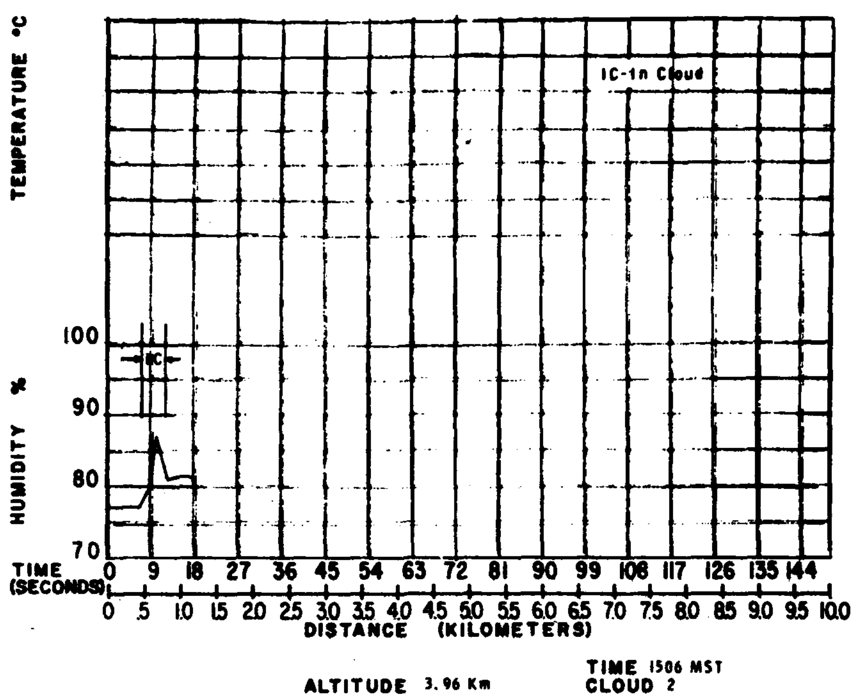

Figure 35. Cloud temperatures and humidities, 20 Jul 66, Flight No. 2, Cloud 2.

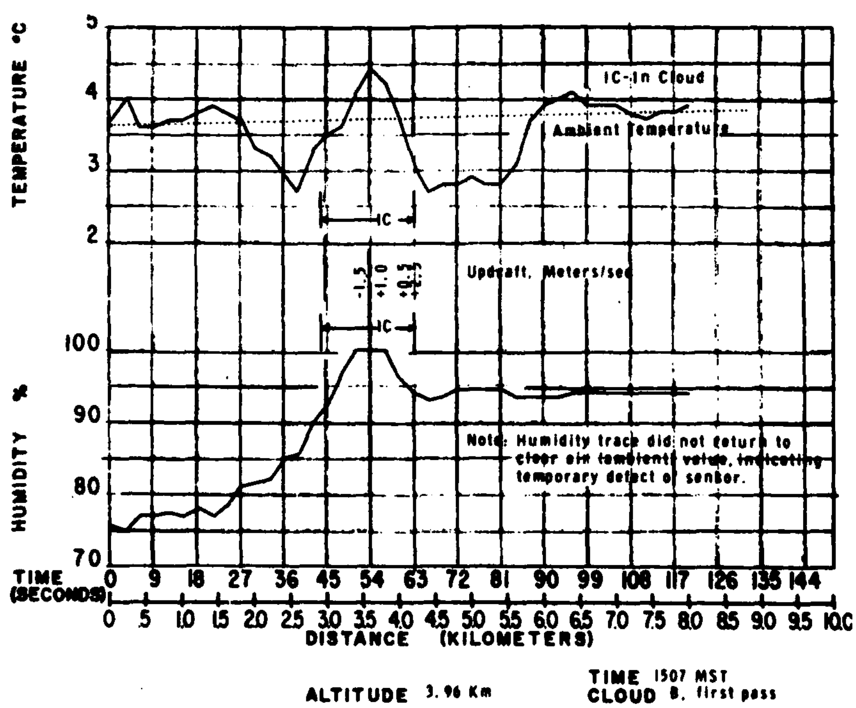

Figure 36. Cloud temperatures and humidities, 20 Jul 66, Flight No. 2, Cloud B (first pass).

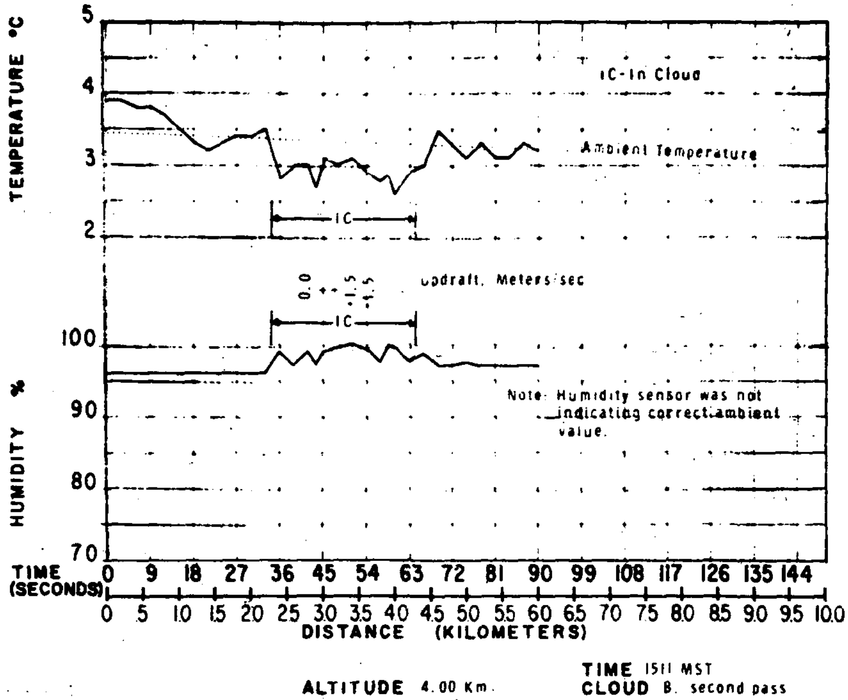

Figure 37. Cloud temperatures and humidities, 20 Jul 66, Flight No. 2, Cloud B (second pass).

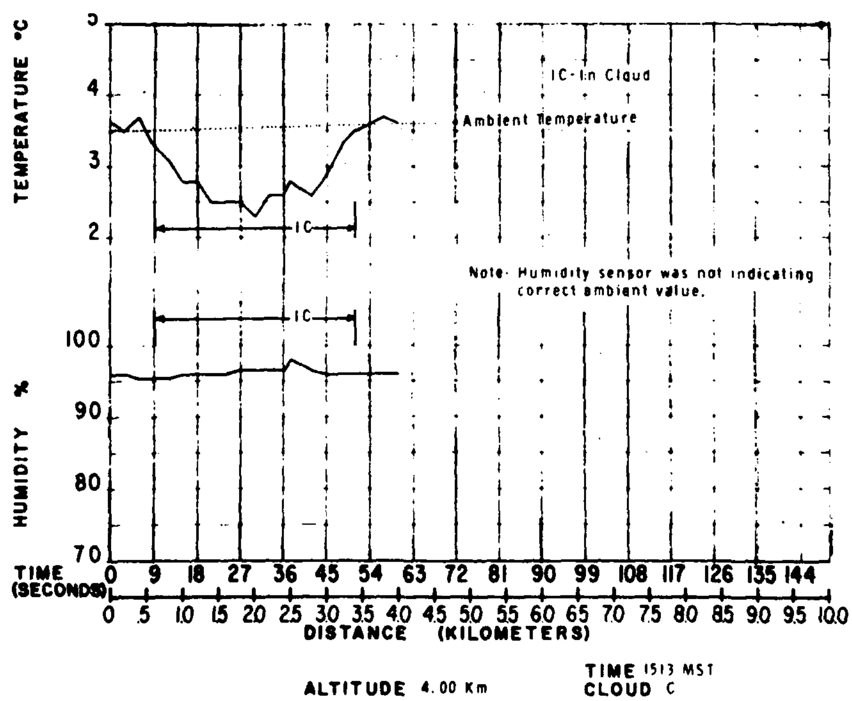

Figure 38. Cloud temperatures and humidities, 20 Jul 66, Figure No. 2, Cloud C.

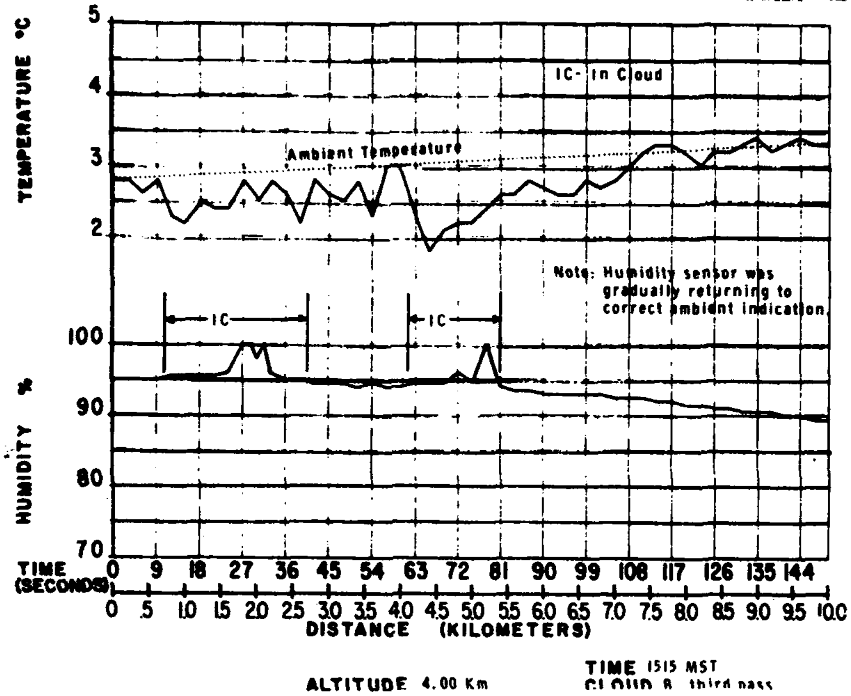

Figure 39. Cloud temperatures and humidities, 20 Jul 66, Flight No. 2, Cloud B (third pass).

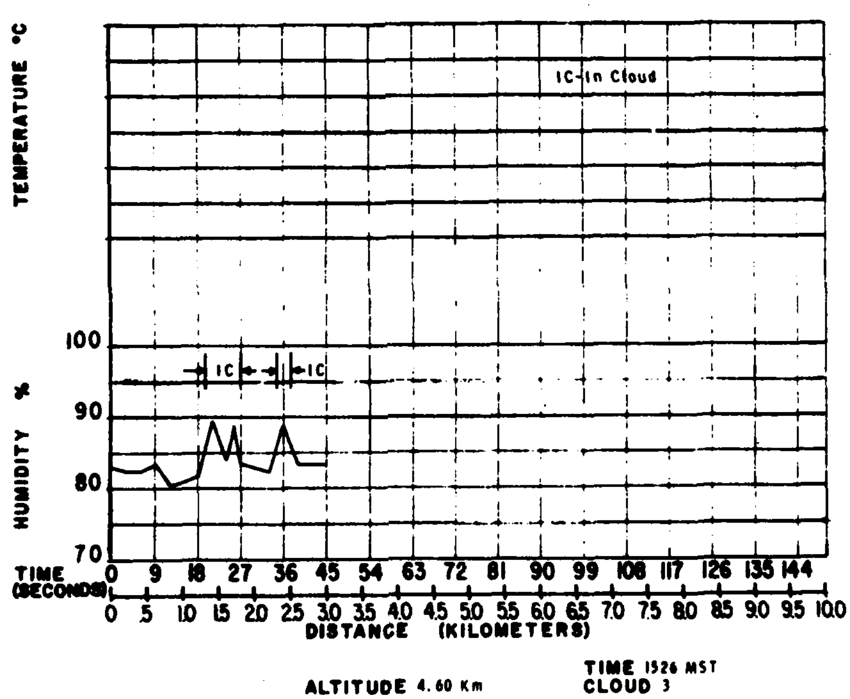

Figure 40. Cloud temperatures and humidities, 20 Jul 66, Flight No. 2, Cloud 3.

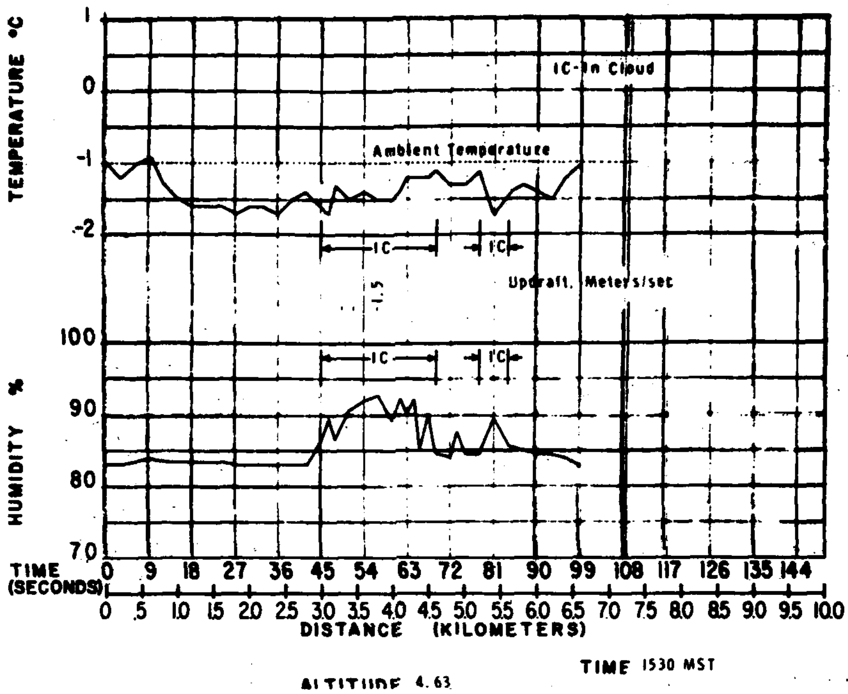

Figure 41. Cloud temperatures and humidities, 20 Jul 66, Flight No. 2, Cloud B (fifth pass).

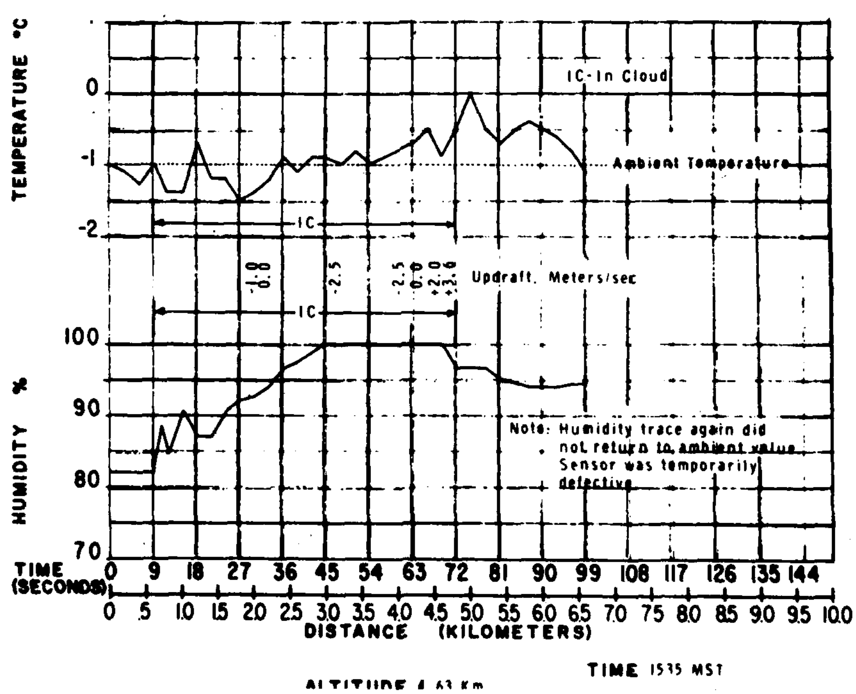

Figure 42. Cloud temperatures and humidities, 20 Jul 66, Flight No. 2, Cloud B (sixth pass).

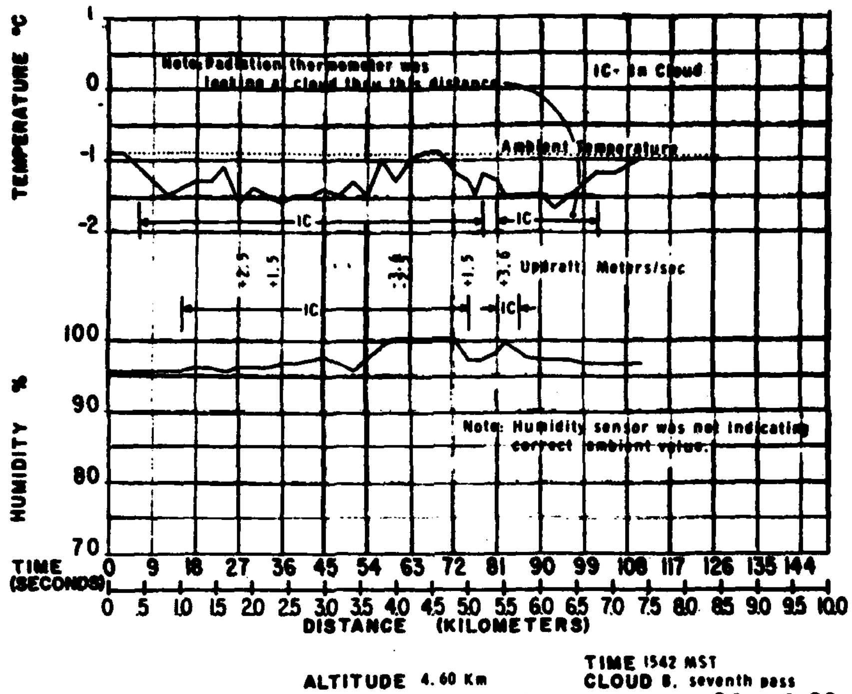

Figure 43. Cloud temperatures and humidities, 20 Jul 66, Flight No. 2, Cloud B (seventh pass).

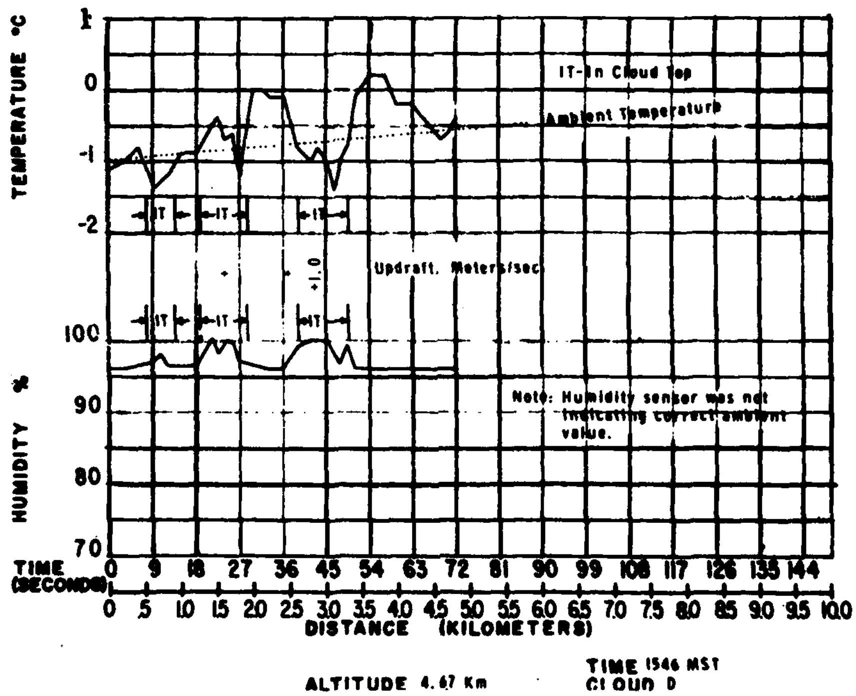

Figure 44. Cloud temperatures and humidities, 20 Jul 66, Flight No. 2, Cloud D.

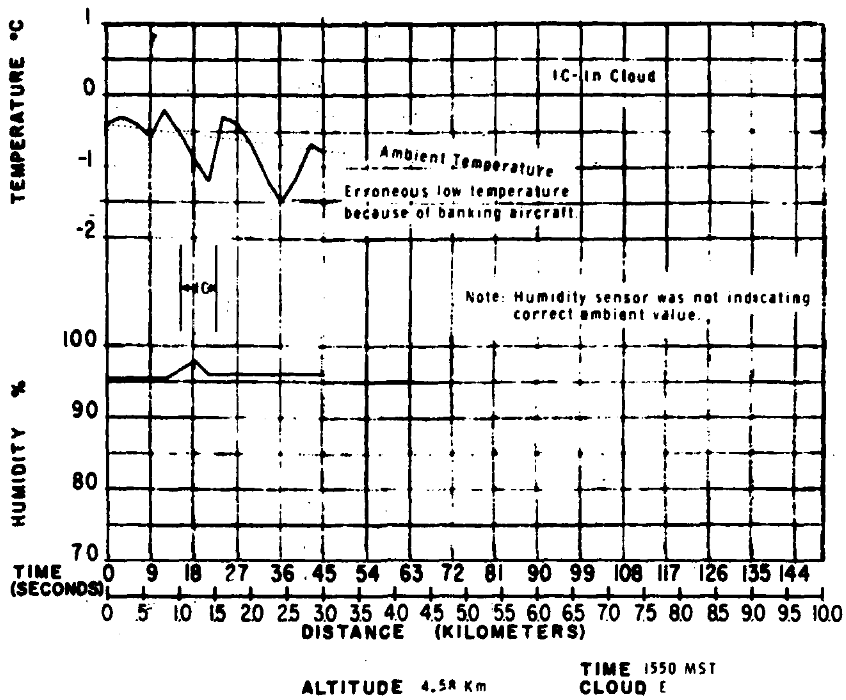

Figure 45. Cloud temperatures and humidities, 20 Jul 66, Flight No. 2, Cloud E.

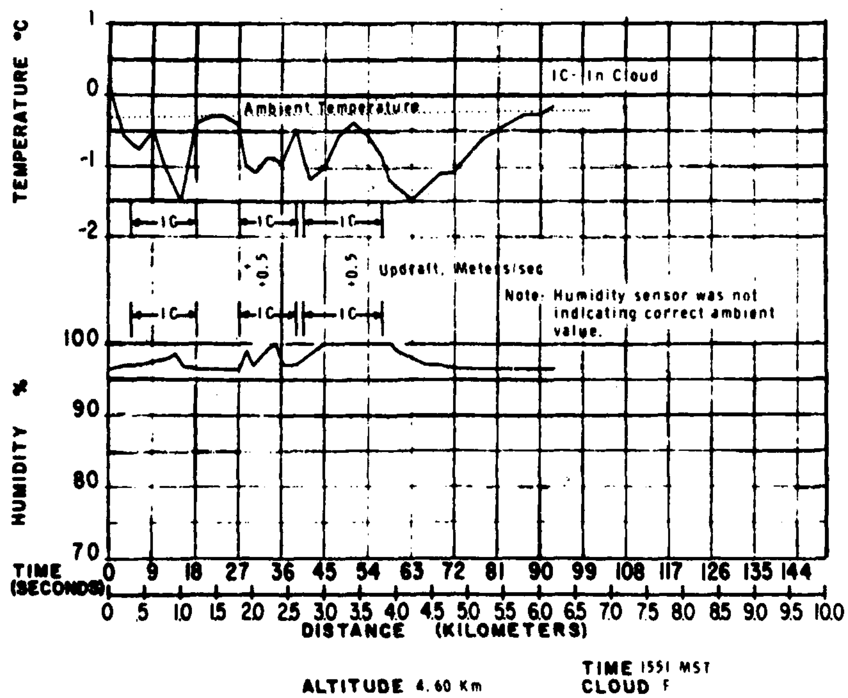

Figure 46. Cloud temperatures and humidities, 20 Jul 66, Flight No. 2, Cloud F.

TABLE I

Variation of Cloud Temperature From Ambient Temperature, July 1966

Date and Flight No.			Degree C	Remarks
UB	15-1	A_1	- 0.5	
		A_2	- 0.7	
		A_3	- 0.7	Average: -0.65°C
	20-2	A1	- 0.5	Range: -0.4 to -1.3°C
		A2	- 0.8	
IB	15-1	B	- 0.4	
	15-2	A	- 1.3	
	19	B	- 0.6	
		C	- 0.6	
	20-1	C	- 0.8	
		D_1	- 0.5	Average: -0.75°C
		D_2	- 0.7	Range: -0.4 to -1.3°C
		D_3	- 1.0	
		E_1	- 0.7	
		E2	- 1.1	
		E_2	- 0.6	
		E_1	- 0.6	
	20-2	Al	- 0.9	
IC	15-2	B	- 1.0	
		Cl	- 1.1	
		C2	- 0.6	
	19	A	- 0.6	
	20-1	A_1	- 0.9	
		A_2	- 0.7	
		B	- 0.5	
		F	- 0.7	Average (excluding *):
		G	- 0.7	-0.85°C
		H	- 0.2	Range: -0.2 to -1.7°C
		I	- 0.6	
		J_2	- 0.8	
		Kl	- 0.9	
		K2	- 1.7	
		L	- 1.4	
		M_1	- 0.9	
		M_2	- 1.1	
		M_3	- 1.1	(Cont'd)

Table I (Cont'd)

Date and Flight No.			Degree C	Remarks
IC	20-2	B1	+ 0.7*)	
		B2	- 0.7)	
		C	- 1.2)	
		B3	- 1.2)	
		B5	- 0.7)	
		B6	- 0.5)	
		B7	- 0.7)	
		E	- 0.6)	
		F	- 1.2)	
IT	20-1	J1	- 0.6	)--- Average: -0.65°C
	20-2	D	- 0.7	)--- Range: -0.6 to -0.7°C

TABLE II

Rise of Temperature Immediately Outside of Cloud, July 1966

Date and Flight No.			Degree C	
			Before Cloud	After Cloud
UB	15-1	A_1	+ 0.2	+ 0.5
		A_2	+ 0.2	+ 0.5
		A_3	0	0
	20-2	A1	+ 0.7	--
		A2	0	+ 0.6
IB	15-1	B	0	0 (+0.6 in cloud)
	15-2	A	0	0
	19	B	0	0
		C	+ 0.1	0.2
	20-1	C	0	0
		D_1	+ 0.3	+ 0.2
		D_2	+ 0.2	+ 0.1
		D_3	+ 0.2	0
		E_1	0	+ 0.8 (Cont'd)

Table II (Cont'd)

Date and Flight No.			Degree C	
			Before Cloud	After Cloud
		E_3	+ 0.8	+ 0.2
		E_2	+ 0.1	+ 0.6
		E_1	0	0
20-2		A_1	--	0
IC	15-2	B	+ 0.3	+ 0.2
		C1	+ 0.5	0
		C2	+ 0.3	0 (+0.6 in cloud)
	19	A	+ 0.3	+ 0.1
	20-1	A1	0	0
		A2	0	+ 0.1
		B	0	0
		F	+ 0.4	0
		G	0	+ 0.6
		H	0	+ 0.6
		I	0	= 0.4
		J_2	+ 0.9	+ 0.6
		K1	+ 0.8	+ 0.6
		K2	+ 0.4	+ 0.2
		L	+ 0.2	+ 0.2
		M_1	0	0
		M_2	0	+ 0.1
		M_3	0	+ 0.6
	20-2	B1	0	- 1.0
		B2	+ 0.1	+ 0.2
		C	+ 0.2	+ 0.1
		B3	0	0
		B5	0	0
		B6	0	+ 1.0
		B7	0	0
		E	+ 0.3	+ 0.3
		F	+ 0.4	0
IT	20-1	J_1	0	+ 0.9
	20-2	D	+ 0.9	+ 0.9

TABLE III

Variation of Ambient Temperatures About The Cloud

Figure No.	Degree C	Horizontal Gradient Degree C/km
9	0.2	-
10	0.2	-
16	0.2	0.35
17	0.2	-
18	0.3	0.15
23	0.7	0.15
29	0.2	-
31	0.3	0.10
39	0.2	-
44	0.3	0.10
45	0.1	0.10

TABLE IV

Rise of Humidity In Traversing Cloud, July 1966

Date and Flight No.			Change (%)	Rise (%)
UB	15-1	A_1	87 - 90	3
		A_2	88 - 91	3
		A3	87½ - 91½	4
	20-2	A1	81½ - 85	3½
		A2	84 - 87½	3½
IB	15-1	B	85 - 92½	7½
	15-2	A	82 - 90	8
	19	B	77 - 89½	12½
		C	82 - 89½	7½
	20-1	C	82 - 89½	7
		1	83 - 88	5
		D_1	84½ - 89½	5
		D_2	82 - 89	7
		D_3	81½ - 91½	10
		E_1	82½ - 89	6½
		E_2	81 - 89½	8½
		E_2	82½ - 90	7½
		E_1	82 - 89½	7½

Table IV (Cont'd)

Date and Flight No.			Change (%)	Rise (%)
	20-2	A1	85 - 86	1
IC	15-1	1	86½ - 91	4½
	15-2	1	83½ - 93½	10
		B	86 - 92½	6½
		2	80 - 98½	18½
		3	85½ - 95½	10
	15-2	4	87½ - 100	12½
		5	86 - 93½	7½
		6	84 - 98	14
		C1	87½ - 98	10½
		C2	86 - 98½	12½
		7	84½ - 100	15½
	19	A	83½ - 91	7½
		1	84 - 95½	11½
	20-1	A1	81 - 88	7
		A2	80½ - 89	8½
		B	82 - 88	6
		2	81 - 89	8
		3	84 - 91	7
		F	84 - 95	11
		G	82 - 92½	10½
		H	83 - 94½	11½
		I	83 - 94	11
		J_2	82½ - 88½	6
		K1	82 - 95	13
		K2	81½ - 93	11½
		L	82 - 95½	13½
		M_1	89 - 95	6
		M_2	89½ - 93½	4
		M_3	89½ - 92	2½
	20-2	1	77 - 84	7
		2	77 - 87	10
		B1	74½ - 100	25½
		B2	(95) - 100	(5)
		C	(95½) - 99	(3½)
		B3	(94½) - 100	(5½)
		3	82½ - 89½	7
		B5	83 - 92½	9½
		B6	82 - 100	18
		B7	(94½) - 100	(5½)
		E	(95½) - 98	(2½)
		F	(95½) - 100	(4½)
IT	20-1	J_1	82½ - 92	9½
	20-2	D	(95) - 100	(5)

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13. ABSTRACT

Temperatures and humidities were measured in aircraft flights in July 1966 at Flagstaff, Arizona. Because of its rapid response and freedom from external influences, an Infrared Atmospheric Thermometer, sensitive to the 15-micrometer wavelength band, was used to provide reliable temperature measurements. Of the 46 traverses through clouds at altitudes up to 5.8 kilometers, all but one showed an interior lower in temperature than the ambient air by as much as 1.7°K. This characteristic seems to be associated with clouds that have ceased growing. Temperatures just below the clouds varied similarly with temperatures inside the clouds, and in about the same magnitudes. The air immediately outside the clouds was always warmer than the ambient air by as much as 1.0°K, except in the one case of the warmer cloud. A barium fluoride electric hygrometer, mounted in a vortex thermometer housing, was used to measure relative humidities. Its rapid response, better than 0.1 second, enabled it to delineate clearly the entry and exit of clouds. Its indication of humidity changes corresponded consistently with temperature changes throughout all flights.

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	ROLE	WT	ROLE	WT	ROLE	WT
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cloud humidity measurements						
thunderstorm clouds						
atmospheric measurements						
moisture content - clouds						
thermal structure - clouds						
infrared thermometer						

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